Design Guidelines for Drinking-Water Systems

2008

Ministry of the Environment

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Ontario

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HISTORICAL NOTE

Since the establishment of the Ontario Water Resources Commission under the Ontario Water Resources Act (1956), the commission engineers used the Ten States Standards for Water Works as the reference design guidelines for sanitary engineering practice. These publications were prepared, edited and published, approximately every five years, by the Great Lakes Upper Mississippi River Board of State Public Health Engineers and Great Lakes Board of Public Health Engineers. The commission engineers had also developed and applied internal advisory water works design guidelines based primarily on the Ten States Standards and included design, construction and operational experience specific to Ontario.

This practice has continued after the establishment of the Ministry of the Environment in 1973. The Province of Ontario joined the Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers and the Ten States Standards Water Supply Committee in 1977.

Over the years, engineering design criteria based on generally accepted good engineering practice in Ontario have been developed and the following ministry guidelines were published:

- Guidelines for the Design of Water Treatment Works (1982)
- Guidelines for Water Distribution Systems (1979, 1985)
- Guidelines for Water Storage Facilities (1979, 1985)
- Guidelines for Servicing in Areas Subject to Adverse Conditions (1985)
- Guidelines for Water Supply for Small Residential Developments (1985)
- Guidelines for Seasonally Operated Water Supply Systems (1985)

These guidelines have been revised and updated based on Ontario-specific engineering practice, the latest Ten States Standards (Recommended Standards for Water Works, 2003) and other relevant North American design guidelines and published as the Design Guidelines for Drinking-Water Systems (2008).

PREAMBLE

The Ontario Ministry of the Environment (***ministry***) *Design Guidelines for Drinking-Water Systems* is intended for an audience that includes engineers who are responsible for designing ***drinking-water systems***, ministry engineers responsible for reviewing and approving the designs of such systems, and the municipalities/owners of the drinking-water systems.

It is intended that this Design Guidelines document be used with professional judgment and experience in the design of drinking-water systems and in the engineering review of applications for approval of such systems. The ministry recognizes that the choice of drinking-water system designs may be influenced during the planning stages by sustainability issues, such as the cost to design and build drinking-water systems as well as the ongoing cost to operate, maintain, rehabilitate and replace infrastructure.

Designers should note that the ministry has a number of specific guidelines and/or procedures which relate to drinking-water systems that may affect design. Such specific guidelines and procedures take precedence over these Design Guidelines.

Similarly, the use of actual site-specific data is encouraged. Wherever possible, designers are encouraged to use actual data derived from the drinking-water system monitoring records and operational studies. Actual data can be compared to the typical values provided in these Design Guidelines for comparison and consideration.

As well, it should be noted that this Design Guidelines document provides design guidance related to established technologies. The fact that other technologies or equipment are not mentioned in the Design Guidelines should not be construed as precluding their use. It is not the intention of the ministry to stifle innovation. The ministry will approve drinking-water system works designs if the applicant and designer can demonstrate that the works will have a reasonable and substantial chance of success for the particular application. However, drinking-water system works designs using new and innovative technologies and equipment would be approved only where operational reliability and effectiveness of the works has been demonstrated with a suitably-sized prototype unit operating at its design load in the conditions suitable for the particular application.

Finally, it must be emphasized that this document contains design guidelines. Legislation, including legislated standards and regulations, takes precedence over the Design Guidelines and must be followed. Readers are cautioned to obtain their own legal advice and guidance in this respect.

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CHAPTER 1

LEGISLATIVE FRAMEWORK

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CHAPTER 1

LEGISLATIVE FRAMEWORK

This chapter provides a brief introduction to some federal and provincial Acts and regulations applicable to the design of drinking-water systems.

1.1 GENERAL

The designer (and proponent) of a drinking-water system are responsible not only for understanding and incorporating all relevant federal and provincial requirements in the planning, design, construction and operation of drinking-water systems, and obtaining professional legal advice with respect to this, but also for being as aware as possible of any pending legislative requirements that may impact design considerations. It is also essential to confirm any legislative requirements with the most up to date version.

1.2 APPLICABLE LEGISLATION ADMINISTERED BY THE MINISTRY

The Environmental Assessment Act (EAA), the Safe Drinking Water Act, 2002 (SDWA), the Ontario Water Resources Act (OWRA), the Clean Water Act, 2006 (CWA), the Environmental Protection Act (EPA) and the Environmental Bill of Rights (EBR) are statutes administered by the Ministry of the Environment (***ministry***). These statutes and their regulations apply or may apply to drinking-water systems. All can be accessed from the Ontario e-Laws website at http://www.e-laws.gov.on.ca/index.html or the ministry website at http://www.ene.gov.on.ca.

The designer should determine which statutes and regulations apply to the proposed drinking-water system or alterations to an existing system and ensure that he/she is familiar with the treatment and design requirements and approvals/permits needed. The designer or municipality/owner should contact the ministry Safe Drinking Water Branch for information regarding applicability of statutes/regulations and applications for approvals/permits.

Where a proposed drinking-water system or alterations to an existing system are a municipal undertaking, it would normally follow the planning processes in the approved Municipal Engineers Association *Municipal Class Environmental Assessment* (MCEA) and thereby meet the requirements of the EAA.

1.3 DRINKING WATER REGULATIONS & SUPPORT DOCUMENTS

The *Drinking-Water Systems* regulation, O. Reg. 170/03 (Drinking-Water Systems) made under the *Safe Drinking Water Act, 2002* (SDWA) outlines minimum requirements for treatment, sampling and monitoring, and other issues which may affect the design of drinking-water systems. The designer should refer to O. Reg. 170/03 and the latest edition of the *Procedure for Disinfection of Drinking Water in Ontario* (***Disinfection Procedure***) (which is adopted into O. Reg. 170/03 by reference) for more information.

Treated water should also meet the *Ontario Drinking-Water Quality Standards* regulation (O. Reg. 169/03) under the *Safe Drinking Water Act, 2002* and the aesthetic objectives and operational goals described in the latest edition of *Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines* (***Technical Support Document***).

For drinking-water systems which are not governed by O. Reg. 170/03, refer to the applicable regulation(s).

1.4 OTHER APPLICABLE LEGISLATION

As of December 1, 2008, five categories of drinking-water systems that were regulated under the *Safe Drinking Water Act, 2002* and O. Reg. 252/05 (Non-Residential and Non-Municipal Seasonal Residential Systems that Do Not Serve a Designated Facility) are now regulated under the *Health Protection and Promotion Act* (HPPA) and its regulations for small drinking water systems [Transitional - Small Drinking Water Systems (O. Reg. 318/08) and Small Drinking Water Systems (O. Reg. 319/08)].

The categories of systems being transferred include large municipal non-residential systems, small municipal non-residential systems, non-municipal seasonal residential systems, large non-municipal non-residential systems and small non-municipal non-residential systems, provided that the system does not serve a designated facility as defined in O. Reg. 170/03 made under the SDWA (e.g. a daycare, nursing home, hospital, school). For details about the requirements for these systems, please see the HPPA and its regulations.

If a drinking water system in one of the above categories does serve a designated facility, it would still be regulated under O. Reg. 170/03 and the SDWA. In addition, some sections of the SDWA will continue to apply to the transferred systems.

Drinking-water systems may be subject to planning-oriented legislation such as the *Planning Act*, the *Municipal Act 2001*, the *Ontario Municipal Board Act* and others. In addition, it may be necessary to obtain approval from a number of other organizations which have jurisdiction over all or part of the project, primarily involving the Ontario Ministry of Labour. Approvals may be necessary from public bodies and authorities such as Ontario Power Generation, municipal plumbing and/or building departments, conservation authorities and the Federal Government (Parks Canada, the Department of Transportation, the Department of Fisheries and Oceans). Liaison with utilities such as telephone, power and gas companies and railways may also be required. Designers should familiarize themselves with the requirements of all legislation dealing with drinking-water systems, including relevant sections of the *Building Code*, the *Electrical Safety Code*, the *Fire Code* and labour health and safety regulations. Existing Ontario legislation may be found at the following "*E-Laws*" website: http://www.e-laws.gov.on.ca. Additionally, although not in force, the *Sustainable Water and Sewage Systems Act, 2002*, is a provincial statute which many municipalities reference when preparing drinking water business plans and when considering the economic viability of proposed projects. The *Financial Plans* regulation (O. Reg. 453/07) under the *Safe Drinking Water Act, 2002*, requires financial plans to be prepared in certain circumstances with respect to drinking-water systems, before a municipal drinking water licence is issued.

1.5 MINISTRY APPROVALS FOR DRINKING-WATER SYSTEMS

The ministry approvals program is designed to ensure that all undertakings requiring approval under the legislation administered by the ministry are carried out in accordance with that legislation (i.e., Acts and Regulations) and the ministry environmental guidelines and procedures developed to ensure consistency of approach to various aspects of environmental protection throughout the Province.

With the proclamation of section 33 of the *Safe Drinking Water Act, 2002* in May of 2007, the ministry began a transition from an approvals process referred to as the Certificate of Approval (C of A) Program for municipal drinking water systems to the new *Municipal Drinking Water Licensing Program* (the Licensing Program). This transition will occur over a period of approximately five years starting in late 2007.

Under the Licensing Program, the authority to establish and alter a drinking-water system will be provided by a ***Drinking Water Works Permit*** (DWWP) and the authority to operate such a system will be provided separately through a ***Municipal Drinking Water Licence*** (Licence).

The requirement to obtain a Licence and a DWWP applies to owners of large and small municipal residential drinking-water systems as defined in O. Reg. 170/03. Owners of these systems must submit to the Director an application for a Licence, an application for a DWWP and completed operational plans on or before the dates prescribed by the *Licensing of Municipal Drinking Water Systems* regulation (O. Reg. 188/07).

Once a Licence has been issued for a drinking-water system, authority for further alterations to the system will occur through the processes and procedures associated with the Licensing Program. Until a Licence is issued for a system, approvals for any alterations to the system will occur through the existing C of A process.

Reference should be made to the ministry's Drinking Water Ontario Portal at http://www.ontario.ca/drinkingwater for further summary information regarding the Licensing Program.

Further information regarding applications for Cs of A can be found in the ministry's publication Guide on Applying for Approvals Related to Municipal and Non-Municipal Drinking Water Systems – Revised November 2003 (PIBS 4467e). The guide describes the approval process in general, clarifies the information required by the respective application forms, and outlines the technical information that may be required in support of various applications.

Further information respecting the applications for the first DWWP and Licence, as well as amendments to these instruments to authorize alterations to a municipal residential drinking-water system once a DWWP and Licence have been issued, will be available on the ministry website as they are developed.

1.6 LEGAL CONSIDERATIONS

The designer should determine which statutes and regulations apply to the drinking-water system and ensure that he/she is familiar with the treatment and design requirements and any approvals/permits needed. There is a wide range of legislation that may apply to the planning, design, construction and operation of drinking-water systems. While some legislation is referenced here no attempt is made to be complete, and the user of the guidelines must obtain legal advice, and understand and abide by any applicable legal requirements.

CHAPTER 2

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CHAPTER 2

PROJECT DESIGN DOCUMENTATION

This chapter provides recommendations regarding documentation associated with the design and construction of drinking-water systems. The planning and the engineering design of ***water works*** varies with the size and complexity of the undertaking and therefore not all documents listed in this chapter may be relevant for a particular project.

The terms used are consistent with the Professional Engineers of Ontario (PEO) *Guideline – Engineering Services to Municipalities (1998).*

The description of technical information and documentation needed to support applications for approvals is provided in the ministry publication *Guide for Applying for Approvals Related to Municipal and Non-municipal Drinking-Water Systems - Parts V and VI of the Safe Drinking Water Act and Drinking-Water Systems Regulation (O.Reg. 170/03),* July 2003 (PIBS 4467e). Information and guidance documents regarding applications for a *Drinking Water Works Permit* (DWWP) under the *Municipal Drinking Water Licensing Program* (the Licensing Program) will be available on the ministry website as they are developed.

2.1 GENERAL

The process of planning and design involves the preparation of a number of separate documents in several stages. The number and complexity of the documents depends on the complexity of the works. The planning and design of new water treatment plants, for instance, requires the preparation of several reports, technical specifications and many drawings. On the other hand, the design of a watermain extension may only require preparation of a single engineering drawing with the basis of design and specifications included on its face.

Stage 1 – Special Services include feasibility and pre-design investigations to determine the best alternative approach to meet the project objectives. Normally, Stage 1 will include feasibility studies, master plans and other special services. For municipal undertakings, the terms of the Municipal Engineers Association *Municipal Class Environmental Assessment* (MCEA), a planning document approved under the EAA for use in planning municipal water works, should be referred to and followed throughout the initial planning process, as and if applicable.

Stage 2 – Preliminary Design and Reports, should include preliminary design information and reports in the form of drawings and documents outlining the nature of the project, a summary of the basis of the engineering design, a preliminary cost estimate and a description of the extent of services and recommendations. In some cases, Stage 2 documents may be prepared as part of the *Environmental Study Report* (ESR) under the MCEA. This work is also sometimes identified as the preliminary 'engineering report', but should not be confused with feasibility studies which are completed in Stage 1.

Stage 3 – Detailed Design, Final Drawings and Specifications, includes preparation of a design brief; final plans (detailed engineering drawings); specifications (construction requirements, materials and equipment); a final cost estimate; and documents required for approval or permit applications (e.g., permits to take water and for construction, liquid waste and air discharges, stream crossings etc.). A report outlining operational requirements may also be required.

2.2 STAGE 1 DOCUMENTS

Most designs will require feasibility or pre-design investigations. If the project is subject to the EAA, the planning and Stage 1 documents should be completed in accordance with the requirements of the MCEA. For projects that do not fall under the EAA, feasibility studies, treatability and pilot studies, pre-design reports and other special services may still be needed, and may consist of the following:

- Geotechnical and hydrogeological investigations;
- Investigations that would locate and identify all potential sources of pollution which could affect source water quality or contaminate the treated water being distributed;
- Preparation of feasibility studies comparing alternatives in terms of factors such as capital, operational and maintenance costs, land requirements, operating efficiency, energy conservation;
- Obtaining topographic plans or photogrammetric mapping; and
- Other special services which may precede the preliminary design and detailed design services described in Stage 2 and Stage 3.

Where the proposed system incorporates processes for which established guidelines are not available, or include equipment and materials where no reliable data from full scale operation are available (e.g., processes that are new or in development – refer to *Section 3.3 – Technology Development*), the following information may also be provided, depending on the scope and risks involved in the project:

- All available data pertaining to the proposed process, equipment or material;
- Results of any testing programs which have been undertaken by groups such as independent testing agencies, research foundations, or universities;
- Identification of any known full-scale applications of the proposed process, equipment and/or material, including a description of the type of application and the name and address of the person who could be contacted for technical information on the application;
- Discussion of the risks and impact of a potential failure of the proposed process/equipment/material and the identification of the measures proposed to be undertaken to preclude any health hazard or non-compliance as a result of such a failure; proposed contingencies to modify or replace the proposed process/equipment/material in case of their failure;
- Description of the monitoring, testing and reporting program proposed to be undertaken during the experimental period; and
- The proposed duration of the experiment.

2.3 STAGE 2 DOCUMENTS

If a Preliminary Design Report is being prepared for the proposed works, it should present the following information, where applicable:

- Description of the proposed works, and where applicable, a description of the associated existing drinking-water system which is intended to be part of the new/expanded system;
- Extent, nature and anticipated population of the area to be serviced, facilities proposed to serve the area (including identification of the sources of water supply), and provisions for future expansion of the system to include additional service areas and/or population growth;
- Itemization and discussion of present and future domestic water consumption figures, commercial and industrial usages, and fire flows used in sizing various components of the water works system;
- Discussion of ***raw water*** quantity requirements and its availability from the proposed source of supply based on a source study. The extent of a

study to determine availability of water will depend on the type and size of the water source, and should be completed in association with the application for a *Permit to Take Water* (PTTW) issued by the appropriate Director appointed under Section 34 of the *Ontario Water Resources Act* (OWRA). For all ***groundwater*** wells, the source study should be a hydrogeologist's report establishing the wells' perennial yields, maximum short-term yields (i.e., 1 day, 7 days, 90 days) and recommended pump sizing based on a hydrogeologist's rating of the long term yields of the wells. The hydrogeologist's report should also deal with possible interference with other existing wells in the area and other natural environmental issues/impacts;

- For systems using or intending to use groundwater wells as a source of raw water, an assessment of the source with respect to it being deemed a ***groundwater under direct influence of surface water*** (GUDI) in accordance with the criteria set out in O. Reg. 170/03 should be undertaken and, if required, a report prepared under the ministry document *Terms of Reference for Hydrogeological Study to Examine Groundwater Sources Potentially Under Direct Influence of Surface Water* (PIBS 4167e). The designer should refer to O. Reg. 170/03 under which some groundwater supplies are deemed to be GUDI, unless a report prepared by a professional hydrogeologist or professional engineer concludes otherwise; and

- Discussion of raw water quality with respect to treatment requirements to meet the *Ontario Drinking-Water Quality Standards* regulation (O. Reg. 169/03) under the *Safe Drinking Water Act, 2002* and the ministry document *Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines* (Technical Support Document), supported by a raw water characterization of parameters listed in the Technical Support Document on a number of raw water samples appropriate for the type of source.

In case of a groundwater source, it is usually sufficient to base the study on several samples obtained during the well pumping tests conducted to establish the yield of the well(s). In order to establish a reliable database for a ***surface water*** source, it is generally necessary to undertake a water sampling and analysis survey extending over a sufficiently long period of time to account for seasonal variations in the water quality.

Normally, the source water analyses should include, at a minimum, all physical, chemical and bacteriological parameters identified in Tables 1, 2 and 4 of the Technical Support Document, and the gross alpha and gross beta screening procedure to determine if it is necessary to undertake further analyses to identify individual radionuclides responsible for the detected radiation (Table 3 of the Technical Support Document). Where general knowledge and/or historical data indicate that particular substances are consistently absent or below the level of concern, these substances/ parameters need not be included in the raw water characterization, provided that the designer documents evidence in support of such exclusion.

The raw water evaluation may also need to include parameters such as conductivity, water stability index, which are not listed in the Technical Support Document, but may be essential in establishing the raw water treatability or other special treatment needs.

- Discussion of the proposed water treatment facilities for the treatment of the raw water in terms of the minimum treatment requirements of *Drinking-Water Systems* regulation (O. Reg. 170/03) under the *Safe Drinking Water Act, 2002* and the *Procedure for Disinfection of Drinking Water in Ontario* (Disinfection Procedure) adopted by O. Reg. 170/03 through reference, and the treated water quality standards and objectives of O. Reg. 169/03 and the Technical Support Document, and a description of treatability work completed. This discussion should include a summary of basic process design parameters of all major components of the treatment facilities, including those such as chemical addition, equipment capacities, retention times, surface settling rates, filtration rates, filter-to-waste capability, and backwash rates as well as the operational reliability of key process units, unit redundancy and back up reliability;

- Evaluation of treated water characteristics and their potential for accelerated corrosion of pipes and appurtenances in the existing or proposed distribution system and plumbing. Refer to *Section 5.1.1 – Blending of Dissimilar Waters/ Treatment Changes* if more than one water source is being considered;

- Discussion of all waste streams generated in the water treatment process, including their volumes, composition, proposed treatment and points of discharge, in terms of effluent criteria established by the proponent in concurrence with the appropriate Regional Office of the ministry;

- Discussion of the proposed instrumentation and control strategy and level of automation;

- Discussion of the proposed flow metering, sampling and monitoring program, including monitoring of any waste streams;

- Description of the proposed pumping facilities (well pumps, and lowlift, highlift and booster pumping stations), including the number and capacities of duty and standby pumps, and discussion of the ability of the system to supply water during power failure events through either standby power facilities and/or elevated storage facilities;

- Discussion of the system storage requirements, including disinfection capabilities and chlorine contact concentration/time (*CT*) requirements, if applicable, and the ability of the proposed facilities to satisfy these requirements;

- Brief discussion of the locations of all significant water works structures with respect to proximity to sources of potential water supply contamination (e.g., sewage treatment plant discharges, sewer overflows, septic systems, impact of major storm events, tributary run-off impacts, runoff from agricultural/livestock rearing areas) and susceptibility to flooding;

- Discussion of the design criteria used for proposed watermains including design flows, minimum and maximum distribution pressures, minimum depth of cover, and minimum separation distance from sewers and other utilities;

- Discussion of the planning for any future extensions and/or improvements to the water supply and distribution system;

- Preliminary design plan(s), all bearing the project title, name of the municipality/owner, name of the development or facility with which the project is associated, name of the design engineer and preparation date, and where applicable, the plan scale, north point, land surveying datum, and any municipal boundaries within the area shown, and providing the following information (where pertinent):

    - General layout and sizes of existing and proposed watermains, and location of major components of other existing and proposed water works and sources of water supply, and points of potential source or system contamination (e.g., sewage treatment plant discharges, sewer overflows, septic systems, runoff from agricultural/livestock rearing areas); and

    - General layout (line diagram) of the works (except for watermains).

- Process flow diagrams for the water treatment processes, showing all process components, the direction of flow of all raw and treated water, recycle and waste streams, the location of all chemical addition points, and the maximum flow of all streams entering and leaving each component of the process and a mass balance for all parameters around each process component; and

- A drawing showing the hydraulic profile through the entire facility including each treatment process.

If these issues were addressed in the ESR, reference should be made to that document.

2.4 STAGE 3 DOCUMENTS

2.4.1 Design Brief/Basis of Design

A design brief, summarizing the design criteria and presenting the design calculations used in sizing individual components of the system, should be prepared along with final plans and specifications. Where a preliminary report was not prepared or where some part of the information in the preliminary report is no longer valid or applicable, the design brief should include the applicable information outlined in *Section 2.3 – Stage 2 Documents* as well as the applicable information outlined below.

2.4.1.1 Design Brief – Major Facilities

Major facilities would include, but not be limited to, water intakes and low lift pumping stations, groundwater wells, water treatment plants, high lift pumping stations, re-chlorination facilities, water storage facilities and booster pumping stations.

- Basic data on the estimated water demand from the population and area to be served, including:
    - Design period;
    - Design service population and area (hectares), and population density;
    - Design per capita water consumption, and industrial and commercial water demand;
    - Fire flow requirements; and
    - Total design water demand (minimum hour, average day, maximum day and peak hour).
- Design flows used in sizing of individual components of the drinking-water system (water intakes, pumps, treatment process units, storage, and distribution facilities);
- Summary of the raw water quality information and the treatment requirements;

- Description (types, number and sizes) of all proposed facilities, process units and equipment, including waste stream treatment and disposal facilities, and identification of their process design parameters (e.g., intake velocity in the intake, mixing energy in rapid mix and flocculation *tanks*, surface settling rates and retention times in settling tanks, filtration and backwash rates in filters, and chemical feed rates);

- Disinfection concentration and contact time (*CT*) information, as well as expected flow characteristics related to CT assessments (e.g. ***T10***) where applicable;

- Detailed process and hydraulic design (or sizing) calculations, including surge analysis (where required) for all facilities, treatment units and equipment;

- Hydraulic profiles through facilities such as water intake, treatment plants, and pumping stations, prepared for minimum and maximum flow conditions to a vertical scale adequate to clearly show the elevations of tank tops, channel and trough inverts, weirs and other features directly affecting the hydraulic gradient (for water intake facilities, normal, maximum and minimum water levels of the water source and their effects on low-lift pumping station should be shown);

- Process flow diagrams (PFD) showing all process components (including type, size, pertinent features, and rate capacity of process units and major equipment, e.g., tanks, reactors, pumps, and chemical feeders), direction of flow of all process, recycle, backwash and waste streams, and the location of all points of chemical addition and treated water and waste stream effluent sampling and monitoring; and indicating the minimum and maximum flow rates of all streams entering and leaving each process component as well as a mass balance for all parameters around each process component;

- Proposed flow metering system, including raw water supply, backwash water flows, individual unit filtration rates, treated water production quantity;

- Proposed chemical flow metering systems, where applicable;

- Proposed treated water and waste stream effluent quality monitoring program, including provision of continuous automatic water quality analyzers, identification of sampling points, frequency of sampling and calibration procedures;

- Proposed system automation and back up procedures (*Section 9.6 – Automated/Unattended Operation*); and
- Proposed rated capacity of the new or expanded water treatment plant (*Section 3.6 – Plant Capacity Rating*).

2.4.1.2 Design Brief – Watermains

- Nature and population of the area served (current and design);
- Maximum water ***demand***, including fire flows;
- Hydraulic grade line profile;
- Design data and calculations for individual watermains, including the required ***capacity***; and
- Capacity of the existing (or proposed) drinking-water system to meet the additional water demand without compromising the system minimum pressure requirements. In cases of minor watermain extensions, where the minimum sizing requirement dictates the use of 150 mm (6 in) diameter pipes, such calculations are generally not required. However, the information is essential where (a) the designer proposes the use of pipe diameter smaller than 150 mm (6 in) for watermains not required to carry fire flow, (b) the uncommitted water supply capability of the existing system is marginal or (c) the proposed water main extension is extensive.

2.4.2 Final Plans & Support Documents

All final plans should bear the project title, name of the municipality/owner, name of the development or facility with which the project is associated, and name of the design engineer, including a signed and dated imprint of his/her Professional Engineer seal, and where applicable, also the plan scale, north point, land surveying datum, and any municipal boundaries within the area shown.

Detailed engineering plans should include plan views, elevations, sections and supplementary views which, together with the specifications and general layout plans, would provide the working information for finalizing the construction contract for the works. These drawings should show dimensions and elevations of structures, ground elevations, the location and outline of equipment, location and size of piping, liquid/water levels, 1:100 year flood line, where applicable, and groundwater levels.

2.4.2.1 Plans of Major Facilities

Major facilities would include, but not be limited to, water intakes and low lift pumping stations, groundwater wells, water treatment plants, high lift pumping stations, re-chlorination facilities and water storage facilities.

General Plan

A comprehensive general plan of the existing and proposed water works should be prepared for all projects involving new major water works. This plan should show:

- Location of the proposed system and the area to be serviced by the system, if applicable;
- All major topographic features including drainage areas, existing and proposed streets, watercourses, contour lines at suitable intervals, municipal boundaries, and land surveying datum used (or assumed bench mark); and
- Location and nature of all existing and proposed major components of the drinking-water system associated with the proposed facilities, including wells, intakes, treatment plant, reservoirs and pumping stations, together with their individual geo-reference coordinates (UTM Easting and Northing).

Site Plans

Individual site plans should be provided for all proposed major facilities of the drinking-water system and modifications/upgrades of such facilities. Each site plan should show:

- The entire property where the facility is to be or is located, including the property lines, and identification of the nature of the adjoining lands;
- Topographic features of the property and adjoining lands, including existing and proposed streets, contour lines at suitable intervals, drainage areas, watercourses, the elevation of the highest known flood level, where applicable, municipal boundaries, and the land surveying datum (or assumed bench mark) used;
- Layout, size and nature of the existing, proposed and future structures on the property showing distances from property lines, and location of residences and other structures on adjoining properties; and
- The location of wells, test borings and groundwater elevations within site limits may be shown on the site plan, depending on the consulting

engineer. The geotechnical report is usually a separate document and a reference should be provided.

General Layout & Detailed Engineering Drawings

The following general layout and detailed engineering drawings should be provided for all new major facilities of the drinking-water system and modifications/upgrades of existing major facilities:

- For each groundwater well, a schematic diagram showing details of well construction including proposed pump installation level, and well screen data including well screen entrance velocities;
- General layout plans for all major facilities of the works (e.g., layout of all filters together) including all associated process flow channels and piping (show direction of flow), process and ancillary equipment, air and chemical feed lines, points of chemical addition, and filter-to-waste;
- Construction scale plan and profile drawings (with dimensions and elevations) of all facilities proposed to be constructed or modified, including any additional descriptive specifications and information not included in a separate specifications document; and
- Process and instrumentation diagrams (P&ID) showing the inter-connection and operational control arrangements for all process and ancillary equipment and appurtenances.

2.4.2.2 Plans of Watermains

General Plan

A comprehensive plan of the existing and proposed components of the drinking-water system should be prepared for projects involving new water distribution systems or substantial additions to existing systems. This plan should show:

- All major topographic features including existing and proposed streets, contour lines at suitable intervals, drainage areas, watercourses, municipal boundaries, and land surveying datum used (or assumed bench mark);
- Location and size of existing and proposed watermains;
- Location and nature of all existing and proposed components of the drinking-water system associated with the proposed watermains; and
- Location of any existing sewer overflows.

Detailed Engineering Drawings

Detailed plan and profile drawings should be provided for the proposed and adjacent existing watermains. The profiles should have a horizontal scale of not more than 1:1000 and a vertical scale of not more than 1:100. The plan view should be drawn to a corresponding horizontal scale. Detailed engineering drawings should show:

- Location of streets and watermains;
- Existing and proposed ground surface;
- Size, material and class of pipe, location of hydrants, valves, blow-offs, meter chambers and other appurtenances;
- Location of all known existing structures which might interfere with or affect the proposed watermains, especially any sewers and other sewage works;
- Details of elements such as watermain bedding and anchoring, hydrant connections, service connections, bridge crossings, stream crossings, support structures for existing structures in the path of construction, trench bracing, thrust blocks, air release valve and blow-off valve installations, and corrosion control measures; and
- Any additional descriptive specifications and information not included in a separate specifications document, but required to inform the contractor of all project requirements regarding the type and quality of construction materials and prefabricated components, quality of workmanship, testing of structures and materials to meet design standards, and acceptance testing for the completed works and component units (e.g., disinfection and pressure testing of watermains).

2.4.2.3 Specifications

Detailed technical specifications should be provided for all water works projects. In the case of minor works such as minor watermain extensions, these specifications can generally be noted on the final plans. For more extensive works, separate specification documents should be prepared.

The specifications should include all construction and installation information not shown on the drawings and required to inform the contractor of all project requirements regarding:

- Type and quality of construction materials and prefabricated components;
- Quality of workmanship and audit procedures/methodology;

- Type, size, rating, operating characteristics, and quality of mechanical and electrical equipment and installations (e.g., process and ancillary equipment and appurtenances, valves, piping and pipe joints; electrical apparatus, wiring, and metering and monitoring equipment, laboratory fixtures and equipment, and special tools);

- Type and quality of process materials (e.g., filter media) and chemicals, as well as applicable American National Standards Institute (ANSI), American Water Works Association (AWWA), NSF International (NSF) and Canadian Standards Association (CSA) requirements;

- Testing of structures, materials and equipment necessary to meet design standards;

- Instrument accuracy and calibration frequency necessary to meet the performance criteria of residual analyzers required by O. Reg. 170/03);

- Acceptance testing for the completed works and component units (e.g., pressure testing of watermains and other piping);

- A program for keeping existing water works facilities in operation during construction of additional facilities so as to minimize interruption of service;

- Laboratory facilities and equipment;

- The number and design of chemical feeding equipment (*Section 6.2.6 – Chemical Feed Equipment and Control*);

- Procedures for flushing, disinfection and testing, as needed, prior to placing the project in service; and

- Materials or proprietary equipment for sanitary or other facilities including any necessary ***backflow*** or ***backsiphonage*** protection.

CHAPTER 3

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CHAPTER 3

GENERAL DESIGN CONSIDERATIONS

This chapter provides an overview of the general design requirements for typical drinking-water systems. The design of a water supply system or treatment process encompasses a broad area and application of this chapter is dependent upon the type of system and processes involved. Additional details are provided in the following chapters.

3.1 GENERAL

The following design guidelines are related to the most commonly used water treatment practices in the province of Ontario. In addition to the guidelines included in the chapter, consideration should be given to the design requirements of other federal, provincial and regional/municipal regulatory agencies, including accessibility, electrical and building code, and construction in the flood plain requirements.

3.1.1 Systems Serving Fewer than 500 People

Although the guidelines are intended primarily for permanent residential developments, they should also be taken into consideration by designers of systems serving seasonal occupancy developments. Seasonal developments may eventually evolve toward extended or full-term occupancy and the drinking-water system should be designed with this possible change in mind.

The decision about whether a communal water supply should be provided rests with the municipality/owner. However, the following recommendations are provided for guidance:

1. Where ten or more residential lots or dwelling units are to be developed or exist and the average lot size is less than 0.8 hectares (2 acres), a communal water supply system should be provided as long as local conditions are favourable to the development of a suitable ground or surface water supply; and
2. In the case of a new subdivision, where the lot size is to be 0.8 hectares (2 acres) or greater, individual wells may be acceptable, unless the subdivision is located within or adjacent to a hamlet or settlement which may be provided with municipal supply in the future. In this case, as a minimum, watermains complete with house connections should be provided at the time of installation of other services. It should be the

decision of the municipality as to whether a communal water supply should be provided in the interim or whether private wells will be allowed.

Systems serving fewer than 500 people may be governed by the *Drinking-Water Systems Regulation* (O. Reg. 170/03), under the *Safe Drinking Water Act, 2002* (SDWA), or other SDWA regulations. The designer should ensure that the requirements of the appropriate regulations are met.

3.2 PRE-DESIGN STUDY

3.2.1 Water Source, Quality & Quantity

In selecting the source of water for a drinking-water system, the designing engineer should ensure that an adequate quantity of water will be available and that the treated water will meet the *Ontario Drinking-Water Quality Standards Regulation* (O. Reg. 169/03) under the *Safe Drinking Water Act, 2002* and O. Reg. 170/03 as well as the *Procedure for Disinfection of Drinking Water in Ontario* (Disinfection Procedure) adopted by O. Reg. 170/03 through reference. The water should also be aesthetically acceptable and palatable. The designer should refer to the latest edition of the *Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines* (Technical Support Document) for a description of operational goals and aesthetic objectives.

In cases where the designer has a choice between two alternate sources, the designer should investigate the source protection and potential development status of each water source, ensure that the water source has sufficient safe yield to provide an adequate quantity of water, and compare treatment requirements and their associated costs prior to selecting a particular source. For municipal drinking-water systems, this is normally done under the provisions of the Municipal Engineers Association *Municipal Class Environmental Assessment* (MCEA) under the *Environmental Assessment Act* (EAA).

Refer to *Section 5.1.1 – Blending of Dissimilar Waters/ Treatment Changes* if more than one water source is being considered.

3.2.2 Risk and the Multi-Barrier Approach

The drinking-water system should have, and continuously maintain, multiple barriers appropriate to the level of risk of contamination facing the raw water supply and the drinking-water system. The main categories of barriers are:

- Source protection;
- Treatment;

- Distribution;
- Monitoring; and
- Responses to adverse conditions, including emergencies.

In addition, multiple barriers may exist within each category of barrier. For example, the treatment barrier may consist of several treatment processes such as coagulation/flocculation, sedimentation, filtration and chemical disinfection, each providing a barrier.

The types of barriers and risk management measures applicable for each water supply will generally be influenced by characteristics of the source water and the ***watershed***, the hazards and an assessment of the risk.

3.3 TECHNOLOGY DEVELOPMENT

Implementation of technologies and re-rating of existing facilities require special considerations. For the purpose of this guide, new technology and proven technology means:

3.3.1 New Technology

Any method, process, or equipment proposed to collect, convey, treat or distribute drinking water that is being tested or has been tested at pilot-scale or at full-scale level, but lacks an established performance record.

3.3.2 Proven Technology

A proven technology has an established performance record and means a technology with:

- A minimum of three separate installations, operated at or near design capacity;
- A minimum of three years of operating record at three separate locations; and
- A minimum of three years operating record showing reliable and consistent compliance with the design performance criteria without major failure of either the process or equipment.

The designer should be aware that new technologies may have a higher risk of failure than proven technologies. The degree of risk of failure can be evaluated through review of sequential stages of a new technology development where the risk of failure is reduced with each of the following subsequent steps:

- Theoretical concept;
- Development at the laboratory or bench-scale;
- Experimental stage consisting of pilot-scale program and field application testing;
- Extensive pilot or full-scale testing; and
- Established performance record.

Only proven technologies should generally be considered for full scale applications to produce drinking water for consumption.

A new technology that is considered for a site-specific application as an experimental or pilot program should meet the following general requirements:

- The size of the principal components and duration of the pilot program should be such that physical, chemical, and/or biological processes are accurately simulated;
- Process variables normally expected in full-scale application have been simulated;
- All recycle streams have been considered;
- Variations in influent raw water characteristics substantially affecting performance in full-scale application have been anticipated and simulated;
- The time of testing has been adequate to ensure process equilibrium and subsequent consistent performance;
- The service life of high maintenance or replacement items has been accurately estimated;
- Basic process safety, environmental and health risks have been considered and found to be within reasonable limits;
- Types and amounts of all required process additives have been determined; and
- A contingency plan should be in place in case of the new technology failing to meet the expected performance.

Designers considering a full-scale application of any new treatment technology should evaluate the above information and other details of any testing programs which have been undertaken by independent testing agencies necessary to ensure the viability of the proposed treatment and document their findings in the Design Brief (*Section 2.4.1 – Design Brief/Basis of Design*). Specific new technologies are not discussed in this guideline.

3.4 DESIGN FLOW

3.4.1 General

In general, water treatment plants should be designed on the basis of projected flows for a 20-year period. For large treatment plants, or where construction cost is an overriding factor, a lesser design period may be selected, but the minimum design period should not be less than 10 years. For intakes and/or outfalls, where the cost of the work is not substantially dependent on the size, a design period in excess of 20 years is recommended. Depending on circumstances, including the reliability of projections, a design to satisfy the ultimate requirements of the official plan for the plant service area under consideration may be appropriate. In all cases, the designer should also consider the flows at the start of the operation of the facilities and the potential for impact on unit process efficiency, delivered treated water quality due to stagnation, as well as flow metering difficulties.

The drinking-water system including the water treatment plant and treated water storage should be designed to satisfy the greater of the following demands:

- Maximum day demand plus fire flow (where ***fire protection*** is to be provided); or,
- ***Peak hour demand***.

The maximum day demand is the average usage on the maximum day. When actual water demand data are available, the designer should review the data and eliminate statistical outliers (e.g., excessive water demands that occurred as a result of a major trunk main break, and erroneous metering or recording) before selecting a value.

The fire flow demand will vary with the size of the municipality (chance of multiple fires at any time) and the nature of development (type of construction materials, building height and area, and density of development). The magnitude of the fire flow allowance is the responsibility of the municipality and the designer should consult with the municipality regarding its fire flow requirements (*Section 8.4 – Sizing of Storage Facilities* and *Section 10.1.2 – Fire Protection*).

The capacity of the treatment processes should be greater than the highest demand (typically maximum day demand) since allowance is needed for water required for in-plant use and process losses. Depending on the processes in the treatment plant, water may be lost as clarifier ***blowdown*** or ***membrane reject*** streams and treated water may be used for practices such as filter washing, service water, and chlorine injectors. Allowance is also needed for filter downtime during a wash cycle. The designer should be particularly careful in designing small treatment plants since in-plant water use can be a significant portion of total production.

The designer should consider the capacity of the plant to ensure that it is possible to produce sufficient water to satisfy the most onerous regularly occurring combination of water demand and raw water quality. This may occur in the spring when raw water quality from surface sources is often worse than average and raw water temperatures are low (reaction times are longer and the efficiency of sedimentation tanks and filters is reduced under peak solids loading). The design should be evaluated against the expected water demand at that time of the year. A most onerous condition also may occur at any time as a result of algal blooms. The designer should review the records for such challenging occurrences (*Section 3.6 – Plant Capacity Rating*).

3.4.2 Domestic Water Demands

Domestic water demands vary greatly from one water system to another. Depending upon such factors as the presence of service metering, lawn-watering practices, use of bleeders to prevent freezing, water quality, water conservation programs and leakage (*Section 3.5 – Water Conservation*), daily per capita consumption can vary from less than 180 L (48 USgal) to more than 1,500 L (396 USgal). For design purposes existing reliable records should be used wherever possible. Domestic water demand used in design historically has ranged from 270 to 450 L/(cap·d) [70 to 120 USgal/(cap·d)]. With increased use of water metering and increased water conservation, the designer may find values at the low end of this range.

Minimum rate, maximum day and peak rate factors for the system should be based on existing flow data, where available. Table 3.1 provides peaking factors for use with average day demand when actual data are not available or are unreliable.

Table 3-1: Peaking Factors

POPULATION	MINIMUM RATE FACTOR (MINIMUM HOUR)	MAXIMUM DAY FACTOR	PEAK RATE FACTOR (PEAK HOUR)
500 - 1 000	0.40	2.75	4.13
1 001 - 2 000	0.45	2.50	3.75
2 001 - 3 000	0.45	2.25	3.38
3 001 - 10 000	0.50	2.00	3.00
10 001 - 25 000	0.60	1.90	2.85
25 001 - 50 000	0.65	1.80	2.70
50 001 - 75 000	0.65	1.75	2.62
75 001 -150 000	0.70	1.65	2.48
greater than 150 000	0.80	1.50	2.25

3.4.3 Commercial and Institutional Water Demands

Institutional and commercial flows should be determined by using historical records, where available. Where no records are available, the values in Table 3.2 should be used. For other commercial and tourist-commercial areas, an allowance of 28 m^3/(ha·d) [3000 USgal/(acre·d)] average flow should be used in the absence of reliable flow data.

When using the above unit demands, maximum day and peak rate factors should be developed. For establishments in operation for only a portion of the day such as schools and shopping plazas, the water usage should also be factored accordingly. For instance, with schools operating for 8 hours per day, the water use rate would be at an average rate of 70 L/(student·day) [19 USgal/(student·day)] x 24/8 or 210 L/student (55 USgal/student) over the 8-hour period of operation. The water use will drop to a residual amount during the remainder of the day. Schools generally do not exhibit large maximum day to average day ratios and a factor of 1.5 will generally cover this variation. For estimation of ***peak demand*** rates, an assessment of the water-using fixtures is generally necessary and a fixture-unit approach should be used.

Table 3-2: Typical Water Demands for Selected Commercial and Institutional Users

COMMERCIAL AND INSTITUTIONAL USE	WATER USE (DAILY AVERAGE)
Shopping Centres (based on total floor area)	2500-5000 L/(m^2·day) [60-120 USgal/(ft^2·day)]
Hospitals	900-1800 L/(bed·day) [240-480 USgal/(bed·day)]
Schools	70-140 L/(student·day) [20-40 USgal/(student·day)]
Travel Trailer Parks (min.with separate hook-ups)	340 L/(space·day) [90 USgal/(space·day)] 800 L/(space·day) [210 USgal/(space·day)]
Campgrounds	225-570 L/(campsite·day) [60-150 USgal/(campsite·day)]
Mobile Home Parks	1000 L/(space·day) [260 USgal/(space·day)]
Motels	150-200 L/(bed-space·day) [40-50 USgal/(bed-space·day)]
Hotels	225 L/(bed-space·day) [60 USgal/(bed-space·day)]

3.4.4 Industrial Water Demands

Industrial water demands are often expressed in terms of water requirements per gross hectare of industrial development when the type of industry is unknown (e.g., new industrial parks). These demands will vary greatly with the type of industry, but common allowances for industrial areas range from 35 m^3/(ha·d) [3740 USgal/(acre·d)] for light industry to 55 m^3/(ha·d) [5880 USgal/(acre·d)] for heavy industry. These are average daily demands. Peak usage rates will generally be 2 to 4 times the average rate depending on factors such as the type of industry and production schedule.

When the type of industry is known, discussions should be held with representatives of the industry to determine water requirements.

3.4.5 Demand Considerations for Systems Serving Fewer than 500 People

3.4.5.1 Household (Interior) Water Demands & Peaking Factors

As a minimum, the water supply/treatment facility should be designed to meet the projected maximum daily flow requirement of the service area with peak hourly, outdoor use and fire demands met from storage. Where it is possible to develop the source of supply to meet more than the projected maximum daily flow, the storage volume can be reduced accordingly.

Average daily domestic consumption rates can vary from less than 180 L/(cap·d) [48 USgal/(cap·d)] to more than 1,500 L/(cap·d) [396 USgal/(cap·d)]. These values represent the average flow over a 24 hour period and do not reflect the fact that there are maximum day and peak hour/instantaneous demands in the system each day which will exceed the average value by a significant amount. It is essential that the source of supply and the distribution system be capable of meeting these maximum and peak demand rates without overtaxing the source or resulting in excessive pressure loss in the distribution system.

In general, small systems have higher peaking factors for maximum day and peak hour demand than large systems. The minimum rate, maximum day and peak rate factors for the system should be based on existing flow data or data from a similar nearby system where available. Table 3.3 provides peaking factors for use with average day demand when actual data are not available.

Table 3-3: Peaking Factors for Drinking-Water Systems Serving Fewer than 500 People

DWELLING UNITS SERVICED	EQUIVALENT POPULATION	NIGHT MINIMUM HOUR FACTOR	MAXIMUM DAY FACTOR	PEAK HOUR FACTOR
10	30	0.1	9.5	14.3
50	150	0.1	4.9	7.4
100	300	0.2	3.6	5.4
150	450	0.3	3.0	4.5
167	500	0.4	2.9	4.3

3.4.5.2 Outdoor Water Use

For outdoor water use, it should be assumed that a maximum of 25% of the homeowners could be using an outdoor tap at any one time at a rate of 20 L/min (5.3 USgpm) for one hour per day. Where fire protection is provided, then this outdoor use need not be considered.

3.4.5.3 Fire Protection

The decision as to whether or not fire protection will be provided via the communal water supply system is a municipal responsibility. In deciding upon the need for such protection, the municipality should consider such factors as the:

- Availability of adequate supply of water;
- Additional capital and operating costs associated with such a system;
- Availability of an adequate fire department, fire service communication and fire safety control facility; and
- Alternatives to a piped communal fire facility such as residential sprinkler systems.

For small systems, the designer should also consider that provision of fire flow can impact residual chlorine in the distribution system due to the need for increased pipe sizes (*Section 10.1.3 – Maintaining Water Quality*).

More information regarding fire protection via the communal water supply is provided in *Section 8.4 – Sizing of Storage Facilities* and *Section 10.1.2 – Fire Protection*.

3.4.5.4 Campgrounds

The peak water usage rates in campgrounds will vary with the type of facilities provided (e.g., showers, flush toilets, and clothes washers) and the ratio of these facilities to the number of campsites. A peaking factor of 4 times average day is recommended and this factor should be applied to the average expected water usage at full occupancy of the campground.

3.5 WATER CONSERVATION

Water conservation and efficiency measures to reduce domestic, industrial, commercial and institutional use of water should be considered along with efforts to estimate and reduce distribution system leakage. Simple estimates for excessive leakage in the distribution system can be obtained by measuring the outflow from storage. The best conditions are after rainfall, when irrigation systems would not be operated, and between the hours of 2:00 and 4:00 a.m. when domestic water use would be at a minimum.

Where flow records or estimates for an existing distribution system suggest that unaccounted-for-water exceeds 15% of average daily demand, then, in consultation with the municipality/owner, an average value within the range of 270 to 450 L/(cap·d) [70 to 120 USgal/(cap·d)] should be considered and the cause of the unaccounted-for-water determined and reduced/eliminated as much as is practical. Metering of water service connections has been found to be effective in controlling excessive water demand, and is therefore recommended by the ministry.

The designer is reminded that, when a *Permit to Take Water* (PTTW) is required, the *Water Taking and Transfer Regulation* (O. Reg. 387/04) made under Section 34 of the OWRA requires that the application for the permit document all water efficiency measures and practices that have been undertaken or will be undertaken for the duration of the PTTW.

3.6 PLANT CAPACITY RATING

3.6.1 Design Capacity

In the case of a new municipal treatment system, a conceptual design ***capacity*** will be developed through the Municipal Engineers Association MCEA process and will be documented in the *Environmental Study Report* (ESR). Once the ESR has met the requirements of the MCEA, this conceptual design capacity will form the basis of detailed engineering design resulting in plans and specifications which, in turn, will be used for obtaining a ***Certificate of Approval*** (C of A) or a *Drinking Water Works Permit* (DWWP) and *Municipal Drinking Water Licence* (Licence)[1] from the approving Director at the ministry. This conceptual design capacity documented in the ESR and confirmed as the proposed rated capacity in the final design brief will be specified in the C of A or DWWP-Licence as the rated capacity of the approved treatment system.

In cases where an expansion, alteration or modification is required to an existing treatment system, the proponent will need to determine the applicable Schedule (Schedule A, B or C) of the MCEA that is relevant to the undertaking. One of the factors in making this determination is the "existing rated capacity" of the "existing water treatment plant" referred to in the Schedules included in Appendix 1 of the MCEA document. This "existing rated capacity" is the rated capacity of the treatment system specified in the existing C of A or DWWP-Licence for the system. If a proposed undertaking involving an expansion, alteration or modification results in treated water flows from the treatment system to the drinking water distribution system that would be beyond the rated capacity stated in the existing C of A or DWWP-Licence, the expanded flow requirements must form the basis of further MCEA considerations and subsequent detailed engineering design.

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[1] With the implementation of the Licensing Program, a Certificate of Approval will be replaced by the combination of a *Drinking Water Works Permit* (DWWP) for the establishment or alteration of the system and a *Municipal Drinking Water Licence* (Licence) to authorize the use and operation of the system

3.6.2 Rated Capacity

The ***rated capacity*** of a water treatment plant is the volume of treated water that meets all applicable Ontario drinking water quality regulations including the aesthetic water quality objectives and that may be made available by the water treatment plant for delivery to the drinking water distribution system in any 24 hour period (usually provided as a rate in m^3/d). Normally, it should be equal to the projected maximum day water demand of the drinking-water system, which is the maximum volume of water required in any 24 hour period during the design period (usually, the next 20 years). The designer should undertake detailed design to meet these requirements in the context of the issues addressed in these design guidelines. The rated capacity of the treatment system will be confirmed in the review of the design by the ministry as part of the C of A or DWWP-Licence application review process, and will be included in the C of A or DWWP-Licence issued after the review is completed.

The rated capacity of a water treatment plant is essentially the net drinking water production rate (i.e. rate of overall drinking water production minus the sum of all in-plant losses and/or demand). The designer is encouraged to consider the following list when determining in-plant losses and/or demand:

- Maximum rate at which water may be withdrawn from the source allowed by the PTTW. This value would take into account all water taking required at the plant;
- Ability of the water treatment plant to consistently produce drinking water meeting all applicable Ontario drinking water regulations as well as aesthetic water quality objectives and other identified site specific treatment needs;
- "Rated capacity" of a water treatment plant is normally distinct from "firm capacity" (*Section 7.3.1 – Firm Capacity and Station Capacity*) of either low lift or high lift pumping. The high lift pumping rate may exceed the plant rated capacity;
- Flow(s) into the treatment system and/or trains and/or stages (the gross daily total, gross instantaneous and net ***instantaneous flow rates*** for each individual treatment process and the overall plant);
- Quantity of reject water associated with treatment processes which would not be available for supply to the distribution system;

- Worst reasonably predictable raw water quality and the periods of time it may occur, and the highest drinking water demand during those periods, considering the:
    - Number of filters out of production for backwash and rest;
    - Volume of water which can be treated through available process trains (e.g. filters and disinfection contact time);
    - Volume of waste water (backwash water, membrane reject water, sludge blow down, chemical make-up water, service water, and any other in-plant treated water uses); and
    - Net flow available for pumping into the distribution system (treated water minus waste water).
- Available volume of the ***clearwell***/reservoir at the water treatment plant and its ability to balance maximum day demand with the rate of flow (m^3/d) into the clearwell; and
- Rated capacity should be established by assessing potential performance of each process in isolation and in conjunction with the entire process train operating as a system to identify the treatment rate of its slowest unit operation – the ***rate controlling step***.

Notwithstanding the above, there could be circumstances where the treatment system has been designed to accommodate, and the C of A or DWWP-Licence may specify, multiple treatment system rated capacities under specified conditions. For example, the capacity of a conventional or membrane filtration plant could have one rating for summer temperatures and a lower rating for winter temperatures. A chlorine contact process could also be a temperature-based rate controlling step with winter flows limited by the CT which can be achieved under cold water conditions. In such cases of multiple specified capacities, the C of A or DWWP-Licence will also specify which of these should be considered the nominal rated capacity for purposes of the MCEA process.

The rated capacity as established in the final design brief would be based on a combination of treatment processes and their performance, including allowances for downtime and redundancy. The designer should document the proposed capacity of each process along with the engineering and water quality parameters on which this capacity is based.

The water treatment plant rated capacity, as defined in the final design brief and subsequently in the C of A, or DWWP-Licence is a point-in-time value. Improvements to operational knowledge and technology, and changes to source water quality and physical facility condition can impact the rated capacity of the plant.

3.6.3 Hydraulic Capacity

The overall water treatment plant hydraulics should be designed for more than the gross flow rates. The designer should consider the sizes of physical hydraulic restrictions (channels, gates, valves, openings, pipe sizes) and consider increasing their hydraulic capacity by 50% over gross flow rates. Equipment and/or provisions should be included in the design so that in the future if process innovations occur, the design would allow the higher flow rate by implementing low cost modifications to the existing plant.

3.7 SITE SELECTION CRITERIA

Municipal water projects are subject to the MCEA and the site selection should be planned according to the requirements of the MCEA, including an evaluation of technical, social, historical/archaeological, natural environment and economic criteria. Whether for municipal or non-municipal facilities, factors which should be considered when selecting a site for new treatment works or the extension of an existing facility include:

- Adequacy of separation from residential areas or other non-compatible land uses;
- Optimum location of the plant with regard to the location of the raw water source and the area to be serviced;
- Susceptibility of the site to flooding;
- Suitability of subsurface and soil conditions;
- Adequacy of the site for future expansion;
- Minimizing adverse environmental impact both during construction and operation of the facility;
- Avoidance of construction adjacent to a shore line except where unavoidable, since suitable measures would be necessary to prevent erosion, and to protect structures from potential wave action or ice-piling; and
- Waste disposal considerations.

Information pertaining to water source selection is provided in *Chapter 4 – Source Development*.

3.8 PLANT/ BUILDING LAYOUT

The general arrangement within the selected site should take into consideration the suitability of subsurface conditions to provide the necessary facilities at minimum cost. Where possible, the designer should take advantage of natural grades in arranging the various process units. Consideration may be given to the use of inter-stage transfer pumps where they are more economical (capital and operating) than extensive construction in adverse ground such as rock.

In the layout of the plant, the designer should locate the buildings to allow adequate flexibility for the economical expansion of the various treatment sections, as well as plant waste treatment and disposal facilities. Plant layout should consider making best advantage of prevailing wind and weather conditions to minimize energy consumption, for example, locating units which need only moderate temperatures on northern exposures.

Plant design should consider functional aspects of the plant layout, access roads, access to the power grid, site grading, site drainage, walks, driveways and chemical delivery and receiving areas. The plant design should also incorporate spill control features for bulk chemical off-loading areas.

Roadways for chemical deliveries should be designed to be sufficient to accommodate the largest anticipated delivery [typically a 27,000 L (7,132 USgal) tank truck], with allowance made for vehicle turning and forward exit from the site. Roadways should be designed for truck traffic in accordance with the Ontario Ministry of Transportation *Ontario Provincial Standards for Roads and Public Works* (OPS).

The design of the building layout should provide for adequate ventilation, lighting, heating and drainage, dehumidification equipment, accessibility of equipment for operation, servicing and removal, flexibility of operation, and operator safety. The plant layout should also allow for the probability of snow drifting, and entrances and roadways should be located to minimize the effect of snow drifting on operations.

Plant designers should also consider all aspects of plant security and layouts that protect critical areas from vandalism or sabotage.

Within the constraints mentioned above, the designer should prepare a plant layout where the various processing units are arranged in a logical progression to avoid the necessity for major pipelines or conduits to transmit water from one module to the next, and also to arrange the plant layout to provide convenience of operation, accessibility of equipment for servicing and removal, as well as to ensure operator safety. Whenever possible, the process units should be located adjacent to each other to minimize the use of space and materials, and to minimize travel distances for maintenance crews. The plant layout should provide adequate protection for all treated water units. The design should include chemical storage and feed equipment in separate room(s) to reduce hazards and dust problems. Chemical storage should be designed for full spill containment and be separate from process structures to ensure that any spills or structural failures for chemical systems will not impact any process streams.

The designer should review all of the above considerations regarding plant/building layout with both the municipality/owner and certified operator at an early stage of the planning and design.

3.9 HYDRAULICS

The design of a new water treatment plant should take into consideration the existing and proposed hydraulic grade lines to determine if raw or treated water pumping will be required. The use of gravity flow can often result in lower capital and operating costs, but may restrict the siting of the treatment facility and may not be suitable for use with some treatment processes. Such factors should be carefully considered to determine the best possible hydraulic and siting configuration such that the treated water quality objectives of the facility are fully met (*Section 3.6.3 – Hydraulic Capacity*).

3.10 ELECTRICAL COMPONENTS

All electrical work should conform to the requirements of the *Canadian Electrical Code* (CSA C22.1-06) and to relevant provincial and/or local codes.

Main switch gear electrical controls should be located above grade in areas not subject to flooding. The designer should consider switchgear facility sizing requirements if variable frequency drive (VFD) type equipment is to be employed.

Consideration should be given to providing voltage stabilization in the electrical services to laboratory and/or sensitive process control equipment, since a relatively constant voltage may be required for proper operation.

3.11 INSTRUMENTATION & CONTROL

Instrumentation and controls should be provided to allow safe and efficient operation of all parts of the drinking water treatment plant and the associated distribution system (*Chapter 9 – Instrumentation and Control*).

3.12 STANDBY POWER

The need for standby power and the extent of equipment requiring operation by standby power should be individually assessed for each water treatment plant and water distribution system. A plan should be developed to ensure that average day demand can be met during a power outage, and that at least an emergency level of lighting and process control operations can be maintained. The plan should take into account the availability of storage capacity in the distribution system (elevated or ground-level storage with standby power).

Some of the factors which should be considered in making the decisions regarding standby power and the process units to be operated by the standby power equipment are as follows:

- Frequency and length of power outages in the area;
- Reliability of primary power source (number of power feeder lines supplying grid system, number of alternate routes within the grid system, and number of alternate transformers through which power could be directed to the water treatment plant);
- Available treated water storage within the system;
- Type of water storage (underground or elevated);
- Requirements for fire protection;
- Type of standby power; and
- Lower level of emissions provided by alternative fuel technologies.

Depending on the complexity of the plant, standby power may or may not be provided for auxiliary services such as lighting, instrumentation and control. In consultation with the municipality/owner, the designer should consider what critical equipment should be operated from the emergency power system to maintain water quality integrity during a power outage.

The designer should be aware that a sustained loss of water supply that allows reservoirs to empty represents a significant risk to public health. As a distribution system dewaters due to continuous water demand, negative or atmospheric pressures are induced, starting at the higher elevations. This creates the potential for uncontrolled backflow, e.g., garden hoses connected to open faucets and an environment in which any exfiltration from a leaky distribution system becomes infiltration, drawing in untreated groundwater.

This is even more acute for direct-pressure systems (i.e., systems without on-line storage).

In designing generator systems, the designer should consider the efficient operation of the engines and whether the plant is staffed at all times or is unattended. Timers should be provided to bring equipment on-line in such a way that the generators are not overloaded by the starting current requirements of motors. Similar protection is necessary to avoid overload of the normal electrical supply on resumption of power following a power failure.

The standby power equipment should be located so that it fits conveniently into the electrical distribution system of the plant. Under some circumstances, it may be preferable to locate the generator set remote from the treatment plant in a separate building to satisfy air and noise requirements under the *Environmental Protection Act* (EPA). Self-contained generator sets that can be pad mounted externally may also be considered.

Engine cooling water may not be returned to any process units. Where cooling water is discharged to a storm sewer system, the designer should ensure that the storm sewer system has adequate capacity, or an alternate diversion of cooling water will be required.

Generator units should be mounted on a pad and surrounded by a containment system to retain any fuel spills. Generator units or fuel storage should not be located above any water treatment process unit or raw or treated water reservoir to avoid any chance of contamination. A clear space for inspection and servicing not less than 1m (3 ft) on all sides of the unit should be provided.

Internal combustion engines used to drive auxiliary pumps, service pumps through special drives, or electrical generating equipment should be located above grade with adequate ventilation of fuel vapours and exhaust gases. Carbon monoxide detectors are recommended where fuel-fired generators are housed.

The designer should refer to the applicable Technical Standards and Safety Authority (TSSA) standards for requirements associated with the safe storage, handling and use of hydrocarbon fuels (such as gasoline, diesel, propane and natural gas).

3.12.1 Diesel Fuel Storage

Sufficient fuel storage should be provided, taking into account the historical data on length of power outages in the area, and any weather or other conditions which might prevent deliveries of fuel. A minimum 500 L (132 USgal) storage should be provided for generator set capacities up to 25 kW and 1,000 L (264 USgal) storage for generator set capacities from 30 to 100 kW.

Either underground or inside fuel storage tanks may be used. Factors such as corrosion potential, leakage and spill protection, storage volume needed and

need for fuel pumps should be evaluated. Fuel storage tanks should not be located above any water reservoir or clearwell. The design of fuel storage tanks and supply lines must conform to all applicable federal and provincial legislation and regulations.

3.13 EMISSIONS OF CONTAMINANTS TO AIR

For all sources of emission of contaminants to the air from drinking-water facilities (e.g., gases from air striping processes, exhaust emissions and noise of diesel generators, and noise of air blowers or compressors) the requirements of Section 9 of the *Environmental Protection Act* (EPA) need to be satisfied.

The *Air Pollution - Local Air Quality* regulation (O. Reg. 419/05), under the EPA, specifies the maximum allowable concentration of specific air contaminants at the ***point of impingement***. Compliance is achieved by maintaining the point of impingement concentrations of the contaminants discharged from the source of emission below the maximum concentrations stipulated in the regulation. Typical points of impingement are the property line and all critical receptors, such as building air intakes or windows.

3.14 PERSONNEL FACILITIES

The personnel facilities needed will be largely dictated by the number and gender of operating staff required and the time periods during which the plant is staffed. As a minimum, it is recommended that provisions be made for storage lockers, preferably two for each employee (one for work clothes, one for clean clothes), and change rooms/washrooms with showers. Water efficient fixtures should be used. A lunch room of adequate size to serve as a meeting or training room for plant staff and a suitable office for plant supervisory staff and record keeping should be provided. Whenever possible, these personnel facilities should be separated from the plant facilities, but with convenient access to the plant.

Drinking water service to most buildings should be provided. Refer to *Section 3.20.4 – Backflow Prevention/ Cross-Connection Control* in this chapter for information regarding backflow prevention.

The provision of drinking water and sanitary facilities for operators may lead to a significant increase in cost for small remote plants. In communities where such facilities may be available elsewhere, the designer should consult with the municipality/owner to determine whether such facilities are required.

3.15 BUILDING SERVICES

All building services should conform to the applicable codes.

Adequate and safe heating systems with controls should be provided. In many areas of the plant, sufficient heat need only be provided to prevent freezing of equipment or treatment processes. Buildings should be well ventilated by means of windows, doors, roof ventilators or other means. All rooms, compartments, pits and other enclosures below grade which must be entered should have adequate forced ventilation provided when it is necessary to enter them. Rooms and galleries containing equipment or piping should be adequately heated, ventilated, and dehumidified to prevent excessive condensation. Switches should be provided for convenient control of the forced ventilation.

Buildings should be adequately lighted throughout by means of natural light and artificial lighting. Control switches should be conveniently placed at each entrance to each room or area. Emergency lighting should be provided.

Communications systems should be provided including connections between buildings.

Power outlets of suitable voltage should be provided at convenient spacing through plant buildings to provide power for purposes such as maintenance equipment and extension lighting. Power outlets located on the outside of buildings may be advantageous. Ground fault interrupter (GFI) type outlets are desirable throughout (where appropriate). Outlets supplied by uninterruptible power supply (UPS) or emergency power systems should be located such that they are easily accessible during a power outage.

Adequate shop space and storage for the designed facilities should be provided. A bridge crane, monorail, lifting hooks, hoist or other adequate facilities should be provided for servicing or removing heavy and/or large equipment.

3.16 SAMPLING & MONITORING EQUIPMENT

Regulatory monitoring requirements are described in the *Drinking-Water Systems* regulation (O. Reg. 170/03) under the *Safe Drinking Water Act, 2002*, as well as the Disinfection Procedure. Smooth-nosed sampling tap(s) should be provided for collection of water samples for both bacteriological and chemical analyses. The sample tap(s) should be easily accessible and located in an area that can be maintained in a sanitary condition. Sample withdrawal lines should be located to provide samples that are representative of the composition of the whole process stream at that point. Sample lines should be stainless steel from the sampling point to the sampling tap. Provisions for back-flushing or cleaning should be made available. The basic sampling locations in a water treatment plant are: raw water prior to any chemical addition; effluent from specific process unit(s); residuals streams; treated water to be delivered to the distribution system. In certain instances, it may be necessary to provide "intermediate" sampling points in a process unit.

On-line process monitoring is discussed in *Section 9.4 – Monitoring*. Additional equipment to monitor the process is described in the following section.

3.17 LABORATORY FACILITIES

Each drinking-water system should have its own equipment and sufficient facilities for routine laboratory testing necessary to ensure proper operation and process control of the system. Laboratory equipment selection should be based on the characteristics of the raw water source and the complexity of the treatment processes involved. Laboratory test kits which simplify procedures for one or more tests may be acceptable. Methods for verifying adequate quality assurances and for routine calibration of equipment should be provided. A certified operator or water quality analyst qualified to perform the necessary laboratory tests is essential; tests which may be performed by a certified operator or water quality analyst are controlled by the *Drinking-Water Testing Services Regulation* (O. Reg. 248/03) under the *Safe Drinking Water Act, 2002*.

Analyses conducted to determine compliance with drinking water regulations must be performed in a drinking water testing laboratory that is licensed under Part VIII of SDWA for classes of parameters indicated.

Sample lines may be used to convey a continuous sample stream to the laboratory from the various stages of the treatment process, for example, raw water, settled water, filtered water and treated water, but not flocculated water. These sample lines should run continuously to provide representative samples and be kept as short as possible. In more remote systems a continuous flow can represent a significant wastewater issue. Where continuous flows are required or are being considered, the designer should also consider carefully how the wastewater will be disposed.

Smooth-nosed sampling tap(s) should be provided. Stainless steel sample lines from the sampling point to the tap are recommended.

3.17.1 Testing Equipment

As a minimum, the following laboratory equipment should be provided:

- Water treatment plants that chlorinate must have test equipment for determining free and total residual chlorine (O. Reg. 170/03);
- All water treatment plants should have a bench or portable nephelometric turbidimeter;
- Each water treatment plant using coagulation, including those which lime soften, should have a pH meter, titration equipment for both hardness and alkalinity, jar test equipment to aid in establishing the optimum coagulant dosage for changing water conditions and test equipment for measuring residual aluminum or iron (depending on the coagulant used);
- Each ion-exchange softening plant and lime softening plant treating only groundwater should have a pH meter and titration equipment for both hardness and alkalinity;
- Each iron and/or manganese removal plant should have test equipment capable of accurately measuring iron to a minimum of 0.01 mg/L, and/or test equipment capable of accurately measuring manganese to a minimum of 0.005 mg/L;
- Water supplies which fluoridate should have test equipment for determining fluoride;
- Water supplies which feed poly and/or orthophosphates should have test equipment capable of accurately measuring phosphates from 0.1 to 5 mg/L;
- Where the process treatment involves reduction of raw water colour, equipment should be provided to determine both true and apparent colour in the raw water and treated water quality ranges; and
- Where UV treatment is used, ready access to a UV meter capable of measuring transmission of 254 nm wavelength light through a path length of 1 cm (0.4 in) of water to an accuracy within +/-2% should be provided.

Sufficient glassware and general reagents should be provided to conduct all the required analyses, as well as appropriate cleaning agents. Sample and reagent storage and refrigeration should also be provided.

3.17.2 Physical Facilities

Sufficient bench space, adequate ventilation, adequate lighting, storage room, laboratory sink, and auxiliary facilities should be provided. Air conditioning may be necessary.

The minimum linear bench space should be 3 m (10 ft), including a wash-up sink. Where space is available, or the size of the laboratory permits, the space should be divided into "dry" and "wet" areas so that sensitive equipment is not subjected to undesirable conditions.

At larger treatment plants, the designer should consider providing pilot-scale facilities, with sufficient flexibility to alter coagulation, flocculation, filtration and other process operations, to assist in determining optimum plant operating conditions. If a pilot plant is not currently being considered, space for future addition should be provided.

3.18 FLOW METERING

All drinking-water systems should have flow measuring devices to measure the flow from each source (well or surface water intake) and conveyed to and through the water treatment plant, the flow of any blended water of different quality and the flow of treated water supplied to the distribution system. In addition, flow through unit processes, backwash flow, chemical and gas flows should be metered for monitoring and controlling the treatment process (*Section 9.4 – Monitoring*).

The designer should consider the importance of meter accuracy, specifically as it relates to compliance with Approval/DWWP-Licence conditions.

In addition, design considerations for flow measuring equipment include:

- Parts in contact with drinking water should be easy to clean and disinfect (*Section 3.26 – Chemicals and Other Water Contacting Materials*);
- Parts in contact with fluids should be suitable for the conditions, including aggressive chemicals or solids that can cause abrasion;
- Instruments should be compatible with the environment in which they are located (e.g., high humidity, temperature, outdoors, and electromagnetic interference);
- Instruments should be located so that they provide accurate and reliable data (e.g., straight pipe requirements upstream and downstream) according to the manufacturer specifications;

- Convenient access to the instrument for maintenance and calibration should be provided. Isolation should be provided so that an instrument can be removed and serviced or replaced. A bypass, pipe spool piece or standby unit should be provided if servicing or calibration will disrupt production;
- Instruments should include a local display;
- Instruments should be selected to provide reliable data over the entire range required; the ***turndown*** of the instrument should be considered in instrument selection. The accuracy and precision required for the process should also be considered (cost generally increases as accuracy increases); and
- Lifecycle cost, including maintenance and calibration requirements and hydraulic head loss (pumping costs), should be considered.

The main process flows are usually measured using mass flowmeters, magnetic, ultrasonic or differential pressure (e.g., venturi) flowmeters. Where low head loss is required, magnetic or ultrasonic meters are preferred. Rotameters are suitable for small flows of liquids and gases. Table 3.4 provides some characteristics of commonly-used flowmeters.

3.19 FACILITY DRINKING WATER SUPPLY

The facility drinking water supply service line should be supplied from a source of treated water at a point downstream of all treatment process units and disinfectant contact time. There should be no ***cross-connections*** between the facility drinking water supply service line and any piping, troughs, tanks or other treatment units containing wastewater, treatment chemicals, or raw or partially treated water. .

3.20 IN-PLANT PIPING

3.20.1 General

All piping used in water treatment plants should be manufactured in accordance with AWWA or CSA standards. Material selection will depend upon economic and corrosion rate factors, as well as the type of equipment used and connections required. The designer should be aware of the greater potential for deflection in thin wall pipe systems than in other systems. Refer to *Section 3.26 – Chemicals and Other Water Contacting Materials* for more information on materials contacting drinking water.

In the design of the piping, allowance should be made for future capacities and also the ease of extending the piping without major disturbance to the

Table 3-4: Commonly Used Flowmeter Characteristics

DESIGN PARAMETER	MAGNETIC	ULTRASONIC	VENTURI TUBE	ROTAMETER
Typical uses	Main process flows or small flows	Main process flows or small flows	Main process flows	Small flows of liquids and gases
Flow range	Up to very large	Up to very large	No theoretical upper limit	Up to 920 m^3/h (4050 USgpm) for liquids; Up to 2210 m^3/h (1300 scfm) for gases
Straight Pipe Requirements (Confirm with manufacturer)	3-5 diameters upstream, 2 -3 diameters downstream	10-20 diameters upstream, 5 diameters downstream	upstream depends on type of upstream fitting and ratio of throat diameter to inlet diameter; 4 diameters downstream	Meter specific; must be installed in vertical position
Accuracy	~ ± 1% (±0.5% at velocities >1m/s)	~ ± 1%	±1% to ±2% with a transmitter	±1% to ±3%

plant. In the general piping arrangement, sufficient space should be provided for piping to be removed, and the pipe design should provide for the proper isolation through valves and pipe sections to allow for repair or replacement. The designer should allow for the possibility that piping could be installed during construction when temperature conditions could be substantially different from the design condition [for example, piping could be installed in temperatures anywhere between 40°C and -20°C (104 °F and -4 °F) and substantial differences in pipe dimensions could occur]. For this reason, the use of polyvinyl chloride (PVC) pipe with cast iron mechanical joint fittings should be avoided. Where piping is cast-in-place, allowance should be made for differential expansion between pipe material and structures. Pipe appurtenances should be of similar materials; otherwise, dielectric couplings should be employed to reduce galvanic corrosion.

Piping should be arranged so that all valves, flow meters, and other items which may require regular inspection or maintenance are conveniently accessible. Piping should be provided with drains at all low points and air-release valves at all high points. ***Sludge*** piping should be provided with clean-outs and flushing facilities.

The design of the piping should allow for proper restraint under all anticipated conditions, particularly where surges may occur and high transient pressures could result or where different temperatures occur seasonally. Supply pressure should be considered and pressure reducing valves employed, where necessary. Plastic or PVC type pipe should be fitted with a shrapnel guard on its entire length if the system is to be operated pneumatically. Plastic or other pipe materials that may shatter on impact should be suitably guarded or protected from physical impact, especially for essential and/or hazardous systems.

Where piping connections are made between adjacent structures, at least one flexible coupling should be provided if any possibility of settlement exists. Particular attention should be given to pipe bedding in areas adjacent to structures to avoid damage due to settlement.

3.20.2 Pipe Sizing

Process water piping should normally be designed for flow velocities as listed in Tables 3.5 and 3.6 with a recommended minimum size of 100 mm (4 in).

Table 3-5: Maximum Velocity Limited by Process Consideration

PROCESS	MAXIMUM VELOCITY (m/s)
Flocculated Water	0.60 (2 ft/s)
Pre-settled Water	0.60 (2 ft/s)
Post-settled Water	0.30 (1 ft/s)
Filter Influent	0.20 (0.7 ft/s)

Table 3-6: Maximum Velocity Limited by Hydraulic Considerations

PROCESS	MAXIMUM VELOCITY (m/s)
Raw Water (pumped)	3.0 (10 ft/s)
Filter Effluent	2.0 (6.6 ft/s)
Wash Supply	3.0 (10 ft/s)
Wash Drains	2.5 (8.2 ft/s)
Treated Water (pumped)	3.0 (10 ft/s)

3.20.3 Piping Identification Requirements

The *Industrial Establishments* regulation (R.R.O 1990, Regulation 851) under the *Occupational Health and Safety Act* (OHSA), makes piping identification, as to contents and flow direction, mandatory for piping systems containing hazardous substances. Identification should comply with the requirements of Canadian General Standards Board (CGSB) standard *CAN/CGSB 24.3-92 Identification of Piping Systems*[2] to simplify operation and maintenance procedures and improve safety. Under this standard, pipes are identified by background, legend, and pictogram colour.

The background and legend, and pictogram colours and code numbers used to identify materials contained in a piping system are provided in Tables 3-7 and 3-8. The code numbers are from CGSB *1-GP-12c Standard Paint Colours, Part 1 Colour Identification and Selection*. Piping may be identified by paint, decals, plastic bands, or polyethylene or detectable ribbon.

Table 3-7: Piping Identification – Background and Legend Colour

CONTENTS CLASSIFICATION	BACKGROUND COLOUR		LEGEND COLOUR	
	Colour	CGSB Equivalent*	Colour	CGSB Equivalent*
Hazardous	Yellow	505-101	Black	512-101
Inherently Low Hazard	Green	503-107	White	513-101
Fire protection	Red	509-102	White	513-101

* Colour numbers are those in CGSB standard 1-GP-12

Where there is no previously existing standard colour code, it is suggested that the guidelines in Tables 3.9, 3.10 and 3.11 be used. Where alternative chemicals are used, it is suggested that a coherent code be developed which consistently identifies the degree of hazard associated with the material contained in the pipe.

3.20.4 Backflow Prevention/ Cross-Connection Control

Within a water treatment plant, considerable potential exists for cross-connections between drinking and non-drinking waters. Typical examples are drinking water supplies for chemical solution make-up, cooling water supplies to mechanical equipment, seal water supplies to pumps and filter surface-wash piping. While pump seal water supplies need only be of better sanitary quality

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[2] The CAN/CGSB 24.3-92 document is not up-to-date and this matter is currently under review.

Table 3-8: Piping Identification – Pictogram Colour

CONTENTS CLASSIFICATION	COLOURS				
	Colour	CGSB Equivalent*		Colour	CGSB Equivalent*
Hazardous	Black	512-101	On	Yellow	505-101
	OR				
	Black	512-101	On	White	513-101
Inherently Low Hazard	Not Applicable				
Fire protection	White	513-101	On	Red	509-102
	OR				
	White	513-101	On	Black	512-101
* Colour numbers are those in CGSB standard 1-GP-12					

Table 3-9: Process Piping Colour Codes

CONTENTS	COLOUR
Raw Water	Dark Blue
Settled Water	Mid Blue
Finished Water	Light Blue
Backwash Waste	Mid Brown
Settled Backwash	Light Brown
Sludge	Dark Brown
Drainage	Light Grey
Sanitary Waste	Black

than the water pumped, it is frequently more convenient to use the treated water system to provide seal water. For information on cross-connection control, refer to the AWWA *Manual of Water Supply Practices M14 – Recommended Practice for Backflow Prevention and Cross-Connection Control* and USEPA *Cross-Connection Control Manual*, 2003.

There are several types of backflow prevention devices available including air gaps, double check valve assemblies, reduced pressure principle devices, dual check valves, atmospheric vacuum breakers and pressure vacuum breakers.

Table 3-10: Chemical Piping Colour Codes

MATERIAL	PRIMARY COLOUR	SECONDARY COLOUR
Aluminum Sulphate	Light Green	-
Ferric Chloride	Light Green	Orange
Silicate Compounds	Light Green	White
Polyelectrolytes	Light Green	Grey
Chlorine Gas*	Yellow	-
Sodium/Calcium Hypochlorite Solution	Yellow	White/Red
Chlorine Dioxide Solution	Yellow	Orange
Lime	White	Orange
Sodium Carbonate	White	Grey
Sodium Bicarbonate	White	Yellow
Carbon Dioxide*	White	-
Alkali Hydroxide	White	Red
Sulphuric Acid	Orange	Red
Sulphur Dioxide*	Orange	-
Ozone*	Brown	-
Potassium Permanganate	Purple	-
Fluoride Chemicals	Purple	Red
Ammonia*	Bright Blue	-
Flammable Gas	Red	-
* All gas solution lines to have light blue secondary.		

For applications involving health hazards, only air gaps or reduced pressure principle devices should be used.

For information on backflow prevention equipment, refer to:

- Applicable municipal by-laws;

Table 3-11: Colour Code Numbers for Process and Chemical Piping

COLOUR	CGSB EQUIVALENT*
Grey	501-103
Light-Grey	501-108
Dark-Blue	502-103
Bight-Blue	502-104
Light-Blue	502-106
Mid-Blue	502-208
Light-Green	503-323
Dark-Brown	504-102
Brown	504-105
Mid-Brown	504-107
Yellow	505-101
Light-Brown	505-206
Orange	508-102
Red	509-102
Purple	511-101
Black	512-101
White	513-101

* Colour numbers are those in CGSB standard 1-GP-12

- Part 7 of Division B of the *Building Code* (O. Reg. 350/06) under the *Building Code Act 1992*;
- *CAN/CSA-B64 SERIES-01 Backflow Preventers and Vacuum Breakers, CAN/CSA-B64.10-01/B64.10.1-01 Manual for the Selection and Installation of Backflow Prevention Devices/Manual for the Maintenance and Field Testing of Backflow Prevention Devices*, and *CAN/CSA-B64.10S1-04/B64.10.1S1-Supplement #1 to CAN/CSA-B64.10-01/CAN/CSA-B64.10.1-01*;
- AWWA *Standard C510: Double Check Valve Backflow Prevention Assembly* and AWWA *Standard C511: Reduced-Pressure Principle Backflow Prevention Assembly*; and

- AWWA *Manual of Water Supply Practices M14 – Recommended Practice for Backflow Prevention and Cross-Connection Control*.

3.21 DISINFECTION AFTER CONSTRUCTION OR REPAIRS

All wells, pipes, tanks and equipment which can convey or store drinking water should be disinfected in accordance with AWWA *Standard C650*-series (*Disinfection of Facilities*) before being placed into operation after construction, maintenance or repairs as required by the *Procedure for Disinfection of Drinking Water in Ontario* (Disinfection Procedure). Plans or specifications should outline the procedure and include the disinfectant dosage, contact time and method of testing the efficacy of the procedure.

3.22 MANUALS & TRAINING

3.22.1 Operations Manual

An operations manual should be supplied to the water works as an essential part of the design. The operations manual should include detailed descriptions and explanations of the treatment process and operational strategies for meeting the requirements of O. Reg. 170/03 and the Disinfection Procedure. All standard operating procedures developed for the plant should be included in the operations manual. The manual should be provided in standard electronic form and cover the following topics:

- A plant overview and process control philosophy statement;
- Detailed unit operations and chemical dosing for normal operation and emergency situations;
- Simplified system schematics that take into account the spatial relationships involved;
- Storage and transmission descriptions and operational procedures;
- Descriptions and operational procedures for facility utilities (HVAC, plant service water, security);
- General safety information, including provisions to keep up-to-date *Material Safety Data Sheets* (MSDS) as set out under the federal *Hazardous Products Act* and associated *Controlled Products Regulations*;
- Spill containment and emergency procedures;
- Emergency power systems and electrical system operation;

- Security of infrastructure, treated water, electronic files and/or programs and response procedures to breaches or intrusions;
- Applicable regulations;
- Monitoring, reporting and documentation procedures;
- Disinfection procedures for bringing equipment on-line after maintenance;
- Reliability and redundancy analysis of system components;
- Detailed routine maintenance procedures;
- Alarm notifications and response procedures;
- A list of emergency contacts and locations of contingency plans; and
- A list of major equipment suppliers.

3.22.2 Equipment Manuals

Equipment manuals including parts lists and parts order forms, operator safety procedures and an operational troubleshooting section should be supplied to the municipality/owner as part of any proprietary unit installed in the facility.

3.22.3 Training

Provisions should be made for operator instruction at the start-up of any new facility, equipment or process, with full documentation.

3.23 SAFETY

Consideration must be given to the safety of water plant personnel and visitors. The designer should refer to all applicable safety codes and regulations, including the *Occupational Health and Safety Act* (OSHA), *Building Code* (O. Reg. 350/06) under the *Building Code Act, 1992* and *Fire Code* (O. Reg. 388/97) under the *Fire Protection and Prevention Act, 1997*. Items to be considered include noise arresters, noise protection, confined space entry, protective equipment and clothing, ergonomics, gas masks, safety showers and eye washes, handrails and guards, ladders, warning signs, smoke detectors, toxic gas detectors and fire extinguishers.

Equipment and chemical suppliers should also be contacted regarding particular hazards of their products and the appropriate steps taken in the facility design to ensure safe operation.

3.24 SECURITY

Design measures to ensure the security of the drinking-water system should be incorporated, installed and instituted. Such measures, as a minimum, should include means to lock all exterior doorways, windows, gates and other entrances to source, treatment and water storage facilities. Other measures may include fencing, signage, closed-circuit monitoring, real-time water quality monitoring and intrusion alarms.

3.25 FLOOD PROTECTION

Other than surface water intakes, all water supply facilities and water treatment plant access roads should be protected to at least the 100 year flood elevation or maximum flood of record.

3.26 CHEMICALS & OTHER WATER CONTACTING MATERIALS

All chemical additives and water contacting materials used in the construction and operation of drinking-water systems should meet all applicable quality standards set by AWWA and, in addition, the consumer safety standards NSF/ANSI[3] *Standard 60: Drinking Water Treatment Chemicals - Health Effects* and NSF/ANSI *Standard 61: Drinking Water System Components - Health Effects*. For uncertified water contacting materials that have been in common and traditional use, such as cement mortar lining or water pipe meeting AWWA specifications, the NSF/ANSI safety certification may not be necessary.

The designer should be aware of the standard condition imposed on Approvals/DWWP-Licences for municipal residential drinking-water systems making the above recommendation a requirement for such systems with the following exceptions:

- Water pipe and pipe fittings meeting AWWA specifications made from ductile iron, cast iron, PVC, fibre and/or steel wire reinforced cement pipe or high density polyethylene (HDPE);
- Articles made of stainless steel, glass, HDPE or Teflon®;
- Cement mortar for watermain lining and for water contacting surfaces of concrete structures made from washed aggregates and Portland cement;
- Food grade oil and lubricants; and

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[3] In Ontario, certification of conformance to NSF/ANSI standards may be provided by one of the agencies approved for this purpose by the Standards Council of Canada.

- Any other material or chemical where the municipality/owner has written documentation signed by the Director that indicates that the ministry is satisfied that the chemical or material is acceptable for use within the drinking-water system and that the chemical or material is only used as permitted by the documentation.

3.27 WATER TREATMENT PLANT RESIDUALS & SANITARY WASTE

The nature and treatability of the waste ***residuals*** to be produced as a result of the treatment processes should be adequately characterized. Waste characterization, in addition to the ultimate disposal requirements, should be given a high degree of consideration in the planning and selection of water treatment processes. Methods of reducing process residual volumes should be considered (*Chapter 11 – Residuals Management*).

All sanitary wastes from water treatment plants, pumping stations, and other water works should be discharged to a sanitary sewer system, a subsurface sewage disposal system or to a sewage treatment facility providing suitable treatment. Sanitary wastes should be kept separate from all process residuals to avoid the need for treatment of all plant residuals in the same manner as sanitary wastes.

3.28 ENERGY CONSERVATION

Typically, the highest energy expenditures in water treatment plants result from high lift pumping. Minimizing energy consumption, while recognizing the need to maintain acceptable water quality, should be included in the design of the distribution system immediately served by the high lift pumps and the selection of the high lift pumping units.

Lighting and HVAC systems consume a significant proportion of the total energy used in a water treatment plant; consideration should therefore be given to energy efficient alternatives or systems. The designer should carefully examine work environment items such as heating, lighting, ventilation, and air conditioning, both in the design and operation stages to ensure that heating and lighting levels are matched to job requirements without safety hazards. Time-delayed switches on lights should be provided in those parts of the plant rarely used, and heating requirements should be reduced not only by adequate insulation in exterior walls, but also by separating areas which need different temperature levels; for example, providing walls between filter operating galleries and filters.

Many organizations and government departments at the municipal, provincial and federal level provide information and guidance with respect to energy conservation. The implementation of water conservation measures, and the resulting decrease in water demand, will also decrease energy usage.

3.29 RELIABILITY & REDUNDANCY

The design of water treatment plants should be based on the premise that failure of any single component must not prevent the drinking-water system from satisfying all applicable regulatory requirements and other site specific treated water quality and quantity criteria, while operating at design flows.

A water treatment plant that is designed with a limited number of treatment barriers, and/or has less treatment contact time than conventional processes, must have a commensurate level of reliability and redundancy of its components.

The designer should consider the following for designing and documenting the reliability of the proposed drinking-water system:

- Regulatory requirements and other site specific treated water quality and quantity criteria during the full range of design flows;
- Likelihood of the system having reduced levels of treatment/performance;
- Risk to the performance of the system and in turn to the environment, public health and safety if the level of treatment and performance of system components is reduced;
- Local conditions and constraints, such as accessibility of the site, reliability and redundancy of the power supply, etc.;
- Manner and methods by which reliability is provided so that reduced treatment or performance and bypasses can be eliminated; and
- Individual process unit/equipment reliability and redundancy analysis to define the following:
  - Critical process unit/equipment;
  - Critical event;
  - Estimated event duration;
  - Actions/safeguards; and
  - Effect on treated water quality and/or quantity.

This reliability and redundancy analysis may be provided using Table 3.12 as an example.

Table 3-12: Reliability Analysis of Water Treatment Plant Components

ELEMENTS	EXAMPLE EVENTS	EVENT DURATION	FREQ-UENCY	ACTION/ SAFEGUARD	EFFECT ON TREATED WATER
Pumps	Pump failure	7 days	1 in 5 years	Firm capacity standby pump off-peak hours storage	None
Chemical System	Components failure	Seconds	1 per year	Alarm, analyzer auto switch; backup system spares	Minimal
	Pump failure	6 hours	1 in 3 years	Auto switch; backup system spares	Minimal
Conventional Filters	Backwash	30 minutes	Daily	Storage at least 3 units	None
	Break through	Minutes	Seasonal	Alarm, turbidity meters on each filter	Yes
Membrane Filters	Integrity failure	Minutes	1 in 3 years	Alarm, particle counter, firm capacity; standby cleaning, storage, lower flux	Yes
	Automatic controls	Seconds			
	Clogging	Minutes			
	Temperature changes	Season	Seasonal		None, low water demand
Power	Power outage	24 hours	1 in 5 years	Alternate grid	None
	Equipment failure	24 hours	1 in 3 years	Generator	None

3.30 OPERABILITY

Drinking-water systems should be designed to ensure ease and reliability of operation and to facilitate maintenance over the life of the facility.

3.31 CONSTRUCTABILITY

The design of the drinking-water system should allow for the following factors:

- Practicality/ease of construction;
- A phased approach;
- Maintaining operations during construction; and
- Planning for future additions/expansion.

3.32 CLIMATIC FACTORS

The designer should consider potential variations in water levels, water temperatures, depth of frost, number of frost free days, depth and duration of snow cover, frequency and size of storm events, as well as other climatic factors associated with climate change.

CHAPTER 4

SOURCE DEVELOPMENT

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CHAPTER 4

SOURCE DEVELOPMENT

This chapter addresses the selection and development of surface and groundwater sources, including water quality and minimum treatment requirements. It also provides guidance on the design of intake structures and wells.

4.1 GENERAL

In selecting the source of water for a drinking-water system, the designing engineer should ensure that an adequate quantity of water will be available, and that the treated water to be delivered to the consumers is in accordance with the requirements of the *Ontario Drinking-Water Quality Standards* regulation (O. Reg. 169/03) and the *Drinking-Water Systems* regulation (O. Reg. 170/03), under the *Safe Drinking Water Act, 2002*, as well as the *Procedure for Disinfection of Drinking Water in Ontario* (Disinfection Procedure) adopted by O. Reg. 170/03 through reference. The treated water should also be aesthetically acceptable and pleasant to drink.

The control of certain unregulated water quality parameters such as taste, odour and colour, should result in drinking water which is clear, colourless and free of objectionable or unpleasant taste or odour. Other aspects of water quality such as corrosiveness, a tendency to form incrustations and excessive soap consumption should be controlled on the basis of economic considerations because of their effects on the distribution system and/or the intended domestic and industrial use of the water. For the assessment of aesthetic water quality objectives and treatment needs, the designer is referred to the ministry document *Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines* (Technical Support Document).

Each water supply should take its raw water from the best available source which is technically possible and economically reasonable to treat to the above standards and objectives.

4.1.1 Source Water Protection

A source water protection plan enacted for protection of groundwater or surface water from potential contamination should be provided as determined by the *Clean Water Act, 2006* (CWA).

4.2 SURFACE WATER

Surface water, in this document, refers to water bodies (lakes, wetlands and ponds, including dug-outs), water courses (rivers, streams, water-filled drainage ditches), infiltration trenches and areas of seasonal wetlands. Many of these locations described as surface water would be unsuitable as a source water supply but are included in the description for full consideration by the designer as these surface water sources may impact the quality of ground water (e.g., GUDI).

4.2.1 Quality

A survey and study should be made of the factors, both natural and human, which may affect water quality. Such survey and study should include, but not be limited to the following elements:

- Determining the degree of control of the watershed area by the municipality/owner;
- Assessing the degree of hazard to the water supply source by agricultural, industrial, recreational and residential activities in the watershed, and by accidental spillage of materials that may be toxic, harmful or detrimental to the treated water quality;
- Identifying and assessing all waste discharges (point source and non-point source) and activities that could impact the water supply source. The location of each waste discharge should be shown on a general plan;
- Obtaining samples over a sufficient period of time to assess variability in the microbiological, physical, chemical and, when applicable, UV transmissivity and radiological characteristics of the water; and
- Consideration of currents, wind and ice conditions, and the impact of other contributing water sources.

4.2.2 Minimum Treatment

As required by O. Reg. 170/03, drinking-water systems that obtain water from a source which is surface water must have a treatment process that is capable of producing water of equal or better quality than a combination of well operated, chemically assisted filtration and disinfection processes would provide. This treatment process must achieve an overall performance that provides, in accordance with the Disinfection Procedure, a minimum of 2-log (99%) removal and/or inactivation of Cryptosporidium oocysts, 3-log (99.9%) removal and/or inactivation of Giardia cysts and 4-log (99.99%) removal and/or inactivation of viruses before the water is delivered to the first consumer.

Higher log removal or inactivation may be needed for a raw water supply where there is a presence of sewage effluent or other sources of microbial contamination, such as runoff from livestock operation, and manure storage, handling or spreading.

The determination of any additional log removal or inactivation required may also be based upon pathogen monitoring of the raw water. For monitoring details, the designer is referred to the United States Environmental Protection Agency (USEPA) guidance manuals *Long Term 1 Enhanced Surface Water Treatment Rule* and *Long Term 2 Enhanced Surface Water Treatment Rule.*

Where necessary, additional treatment should be provided to ensure that the finished water meets the health based standards described in O. Reg. 169/03, and to satisfy aesthetic water quality objectives in accordance with the Technical Support Document.

4.2.3 Intake Location

The design objective in locating the intake should be to provide adequate quantities and a high and consistent quality of raw water, as confirmed by samples taken over four seasons at the location and depth of the proposed intake.

All available water quality information should be examined and the designer should take particular note of both present and future planned outfalls from sewage treatment plants and industrial installations, as well as any inshore pollution, especially during high run-off conditions. Data on current flows and directions should be reviewed, as well as potentially infrequent occurrences such as thermoclines or falling plume dispersions, to determine an intake location that would provide the highest quality water.

Zebra mussels and other molluscs may impact intakes and should be assessed at the proposed location in the water source.

The final intake location will be affected by bottom contours, subsoils and available water depths. The submerged depth will also depend on the type of shipping, if any, which frequents the general location. The designer is referred to the *Navigable Waters Protection Act* for guidance. The minimum submergence from top of intake structure to minimum recorded water level should be 3m (10 ft) wherever possible.

4.2.4 Intake Structures

Because of the difficulty and high cost of marine construction, it is suggested that intake size be sufficient for the projected plant requirement for an extended design period. This will often result in only a single size difference in the intake when compared to a 20-year design period. The hydraulic design for the intake for its final capacity should assume a Hazen-Williams coefficient, C, of 100.

The intake design and its anchoring should take into account peak wave height and frequency, and provide adequate protection against ice scouring and dragging anchors.

The designer should obtain historical information on water depths at the proposed location and determine whether or not the source level is controlled and also whether historical minima occurred before or after control measures were implemented.

The designer should consider the potential occurrence of frazil ice on intakes when determining crib design and inlet velocities. Intake crib materials should be of low thermal conductivity, with racks of smooth materials. The design should provide for low entry velocities – below 75 mm/s (3 in/s) – and uniform acceleration of water from inlet to intake pipe.

Entrance ports to intakes should be located to prevent sediments from being picked up. Both top entry and side entry designs are acceptable and may be evaluated on the basis that:

- Side entry designs are less likely to be damaged by anchors; and
- Top entry designs provide greater clearance above the river or lake bottom, and the required inlet area can be more readily attained.

All designs should be checked for transient pressure problems, particularly if the intake pipe is long or has high design velocities.

For small intakes, consideration should be given to providing means for back-flushing the intake, if practical.

The designer should consider the need for duplicate intakes, particularly where:

- Damage to an intake may occur by objects such as anchors and nets;
- A second intake provides redundancy in the event of changes in water quality caused by thermoclines; and

- Ambient water quality prevents the use of chlorine for mussel control. Where deemed necessary, provisions should be made in the intake structure to control the influx of mussels or other aquatic nuisances (*Section 4.2.5 – Mussel Control*).

Under certain circumstances, an intake may not be necessary and a forebay may be constructed. The designer should ensure that sufficient depth of water will exist in the forebay under any source conditions, and that the bay can remain relatively clear of ice.

The design of river intakes differs substantially from that for lakes in that a substantial current may exist and both anchoring and bottom scouring considerations will assume greater significance. Where possible, river intakes should ideally be located well upstream of known point sources of pollution.

The design of intake structures should also provide for:

- Withdrawal of water from more than one level if quality varies with depth and during seasonal events;
- Inspection manholes for pipe sizes large enough to permit visual inspection and/or diver entry for larger intakes; and
- Occasional cleaning of the inlet line.

A diversion device capable of keeping large quantities of fish or debris from entering the intake structure should be provided.

When buried surface water collectors are used, sufficient intake opening area should be provided to minimize inlet headloss. Particular attention should be given to the selection of backfill material in relation to the collector pipe slot size and gradation of the native material over the collector system.

Refer to *Section 7.4.1 – Raw Water Pumping* and *Section 7.5.1 – Raw Water Pumping* (for systems serving fewer than 500 people) for more information regarding the design of raw water pumping stations. Where the intake or well is remote from the treatment plant, refer to *Section 9.6 – Automated/Unattended Operation* for information regarding the design of instrumentation and control systems for remote operation.

4.2.5 Mussel Control

Mussels have the potential to obstruct public water supply intakes and cause loss of intake capacity, as well as contribute to taste and odour problems. Water suppliers should periodically assess the condition of their intakes to determine if mussels are or potentially may be present and implement a system of control.

The most accepted and currently recommended forms of chemical treatment for public water supplies are the use of oxidants such as chlorine, chlorine dioxide, potassium permanganate and ozone. Chemical dosages are typically applied at the intake through solution piping and a diffuser to prevent the formation of mussel colonies within the intake and piping. The type of chemical selected and frequency of application will depend on the type of existing chemical treatment facilities, mussel breeding season, potential for trihalomethane (THM) formation, other pre-treatment objectives such as taste and odour control, safety and economy.

In addition to the chemical methods described above, intake screens manufactured with special alloys that prevent the growth of zebra mussels on the intake itself are also available.

The following items should be addressed in the design of a mussel control system:

- Solution piping and diffusers should be positively anchored. Piping should have appropriate valving and should be installed within the intake pipe or in a suitable carrier pipe;
- A spare solution line should be provided for redundancy;
- Chemical feeders should be interlocked with plant system controls to shut down automatically when raw water flows stop;
- Provisions should be included for obtaining raw water samples not influenced by chemical treatment;
- Means to provide adequate flushing; and
- The designer may wish to consider the provision of a suitable alternate intake, as periodic alternating use/zero flow conditions has been demonstrated to control mussel infestation, where economical.

4.2.6 Impoundments & Reservoirs

Although uncommon in the Province of Ontario, the implementation of source water protection legislation may create a need for impoundments or reservoirs for a number of drinking-water systems.

The designer should be aware that changes in water quality may occur in impoundments and/or reservoirs, and the intake(s) should be designed accordingly.

Impoundments and reservoirs should be adequately secured through the use of fencing, signage and/or patrolling, if necessary.

4.3 GROUNDWATER

4.3.1 General

While other sections of these guidelines apply equally to surface water sources and groundwater sources, there are a number of special considerations which relate to groundwater systems that should be reviewed by the designer.

For the purpose of defining minimum treatment of groundwater, a raw water supply which is groundwater means water located in subsurface aquifer(s) where the geological materials (sediments) act as an effective filter that removes micro-organisms and other particles by straining and natural attenuation of potential pathogens, to a level where the water supply may already be potable but disinfection is required as an additional health risk barrier.

Groundwater under direct influence of surface water (GUDI) means groundwater having incomplete or undependable subsurface filtration of surface water and infiltrating precipitation. The designer should refer to O. Reg. 170/03 under which some groundwater supplies are deemed to be groundwater under the direct influence of surface water systems, unless a report prepared by a professional hydrogeologist proves otherwise.

4.3.2 Hydrogeological Studies (GUDI or Groundwater Sources)

Prior to the design of a supply structure, adequate geological, hydrological and water quality studies on the aquifer should be carried out to assess the suitability of the source and confirm that the proposed groundwater supply is not a groundwater under the direct influence of surface water. The report should be prepared by or under the direction of a qualified hydrogeologist.

In particular, the studies should address such factors as establishing the wells' perennial yields, maximum short-term yields (i.e., over 1 day, 7 days or 90 days) and recommended pump sizing based on a hydrogeologist's rating of the long term yields of the wells. This report should also deal with possible interference with other existing wells in the area and the potential for contamination by surface water. Where there is concern about contamination, an assessment should be completed based on the ministry document *Terms of*

Reference for Hydrogeological Study to Examine Groundwater Sources Potentially Under Direct Influence of Surface Water (PIBS 4167e).

4.3.3 Minimum Treatment

The minimum treatment for groundwater (that is not GUDI) is disinfection. This treatment process must achieve an overall performance that provides, in accordance with the Disinfection Procedure, a minimum of 2-log (99%) removal and/or inactivation of viruses before the water is delivered to the first consumer.

Where necessary, additional treatment should be provided to ensure that the finished water meets the health based standards described in O. Reg. 169/03 and to satisfy aesthetic water quality objectives in accordance with *Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines* (Technical Support Document) .

4.3.4 Wellhead Protection

The designer should prepare a wellhead protection plan for continued protection of the water supply from potential sources of contamination, such as mechanical protection or run-off diversion, in accordance with the requirements of the ministry document *Protocol for Delineation of Wellhead Protection Areas for Municipal Groundwater Supply Wells under Direct Influence of Surface Water* (PIBS 4168e).

4.4 GROUNDWATER UNDER THE DIRECT INFLUENCE OF SURFACE WATER

4.4.1 Minimum Treatment

In accordance with O. Reg. 170/03, drinking-water systems that obtain water from a raw water supply which is GUDI should have a treatment process that is capable of producing water of equal or better quality than a combination of well operated, chemically assisted filtration and disinfection processes would provide. This treatment process must achieve an overall performance that provides, in accordance with the Disinfection Procedure, a minimum of 2-log (99%) removal and/or inactivation of Cryptosporidium oocysts, 3-log (99.9%) removal and/or inactivation of Giardia cysts and 4-log (99.99%) removal and/or inactivation of viruses before the water is delivered to the first consumer.

Where necessary, additional treatment should be provided to ensure that the finished water meets the health based standards described in O. Reg. 169/03, and to satisfy aesthetic water quality objectives in accordance with the Technical Support Document.

4.4.1.1 Bank Filtration (Shore Wells)

Bank filtration is best suited to systems that are located adjacent to rivers with reasonably good surface water quality and that plan to use bank filtration as one component of their treatment process. For certain systems, bank filtration can be an efficient, cost-effective pre-treatment option to improve water quality or control the extent of sudden changes in raw water temperature and quality after a storm event; however, only certain sub-surface conditions provide improved quality.

The designer should consider the type of bed and aquifer material present, the dynamics of groundwater flow, and the potential for scouring of riverbed materials at any potential bank filtration site. The degree to which any particular ***contaminant*** will be removed via bank filtration depends on site-specific conditions and may vary over time. A similar raw water characterization as for surface water may apply.

4.4.2 GUDI with In-Situ Filtration

When a hydrologeologist report prepared in accordance with the ministry document *Terms of Reference for Hydrogeological Study to Examine Groundwater Sources Potentially Under Direct Influence of Surface Water* (PIBS 4167e) concludes, and the Director agrees, that adequate in-situ filtration is provided by the geological materials (sediments), and adequate wellhead protection measures are being provided, the required minimum treatment may be achieved, without chemically-assisted filtration, through disinfection alone.

The disinfection process or combination of disinfection processes should be capable of providing the required inactivation of oocysts, cysts, and viruses. To achieve the overall performance specified above, the designer may use a combination of both ultraviolet disinfection and chemical disinfection.

The development and implementation of microbial contamination control plans, subject to approval by the ministry, is required for residential drinking-water systems using GUDI with effective in situ filtration where the municipality chooses not to provide chemically assisted filtration, or equivalent treatment, ahead of disinfection. The designer is referred to the ministry document *Development of Microbial Contamination Control Plans for Municipal Groundwater Supply Wells under Direct Influence of Surface Water with Effective in situ Filtration*[4] (PIBS 4008e) for more detailed information.

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[4] *Development of Microbial Contamination Control Plans for Municipal Groundwater Supply Wells under Direct Influence of Surface Water with Effective in situ Filtration*(PIBS 4008e) comprises two documents, Reference

4.5 WELLS

4.5.1 Wells Design

The design objectives for a well should be to provide a hydraulically efficient and structurally sound well that will produce the required water quantity on a continuous basis, and which is protected from external contamination.

For specific details of yield and drawdown tests in addition to design and construction criteria, the designer should refer to the *Wells Regulation* (R.R.O. 1990, Regulation. 903 as amended) under *Ontario Water Resources Act* and AWWA *Standard A100: Water Wells*.

The scope of the hydrogeological study undertaken to determine the aquifer and well yields should take into account the requirements of the *Permit to Take Water* (PTTW) program under Section 34 of the OWRA.

4.5.2 Well Pumphouse Design

In general, the design criteria for well pumping stations follow those presented for raw and treated water pumping stations. In addition, the following special considerations apply to wells. The use of well pits to house pumping equipment is discouraged because of the maintenance and safety problems associated with this type of construction.

For lineshaft pumps, a pedestal should be provided around the casing to support the full weight of the pump and to prevent any weight from being placed on the working casing or any associated well casing. Submersible pumps may be supported by the casing.

Where wells are completed in flowing artesian conditions, piezometric control of the aquifer is required. This may be achieved by installing a suitably sized, valved discharge-to-waste line to convey water from the inner well casing to outside the building. Flow to waste is discouraged, where possible.

A watertight seal should be provided between the pump base plate or submersible discharge head and the pump pedestal or between the well casing and the pump discharge column to prevent the entrance of contaminants.

An aperture for air venting must be provided to the inner well casing. Where there are indications of excessive quantities of explosive or toxic gases in the water, the pumphouse should be vented to the outside.

Document (PIBS 5022e) and Guidance Document (PIBS 5023e), and is available in electronic (PDF) format from the ministry Public Information Centre or Drinking Water Management Division, Safe Drinking Water Branch.

For wells housed within a pumphouse, the well should be located within 1.2 m (4 ft) of an exterior wall of the pumphouse and centred under a hatchway in the roof, at least one metre square, to facilitate access by crane.

The piping layout in the pumphouse should include an in-line free discharge pipe to the outside of the building to permit future testing of the well. The end of the pipe should be equipped with a free discharge pipe orifice and manometer tap, calibrated to the design yield of the well. If high static water levels exist, the designer should consider the use of a by-pass to waste from the pump to avoid transient high discharge pressures on start-up.

A combination flow controller, with pressure gauges upstream and downstream, a suitable check valve and an indicating flow meter should be installed in advance of the free discharge pipe.

A suitable sampling point should be provided upstream of chemical addition for monitoring well water quality. Water level monitoring equipment should be provided by including at least one opening in the well head, typically 25 mm (1 in) diameter, which allows vertical access to the inner casing for equipment installations.

Wells equipped with line shaft pumps should have the casing firmly connected to the pump structure or have the casing inserted into a recess extending at least 10 mm (0.4 in) into the pump base. The pump foundation and base should be designed to prevent water from coming into contact with the joint. Oil lubricants, if necessary, should be food grade.

Where a submersible pump is used, the top of the casing should be effectively sealed against the entrance of water under all conditions of vibration or movement of conductors or cables. The electrical cable should be firmly attached to the riser pipe at 6 m (20 ft) intervals or less.

The discharge piping should be designed so that the friction loss will be low, and have control valves and appurtenances located above the pumphouse floor when an above-ground discharge is provided. Piping should be protected against the entrance of contamination. Discharge piping should be equipped with a check valve in or at the well, a shutoff valve, a pressure gauge, a means of measuring flow, and a smooth nosed sampling tap located at a point where positive pressure is maintained.

Where applicable, the discharge piping should be equipped with an air release-vacuum relief valve located upstream from the check valve. An air gap of at least 150 mm (6 in) or two pipe diameters, whichever is greater, should be provided between the exhaust/relief piping and the flood rim.

Appropriate valving should be provided to permit test pumping and control of each well.

All exposed piping, valves and appurtenances should be protected against physical damage and freezing.

Piping should be properly anchored to prevent movement and be protected against transient pressure.

The discharge piping should be provided with a means of pumping to waste or discharge to irrigation through an air gap backflow preventer. The provision of facilities for regular, short duration discharges to waste on pump starts can have a highly beneficial effect on distribution system maintenance requirements where iron, manganese or sediment are present.

4.5.3 Decommissioning Wells

Unless used for monitoring, all test holes, wells or partially completed wells should be properly abandoned or decommissioned in accordance with the requirements of *Wells Regulation* (R.R.O. 1990, Regulation 903 as amended) under the *Ontario Water Resources Act*.

CHAPTER 5

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CHAPTER 5

TREATMENT

This chapter describes design considerations for various water treatment processes. The design of treatment processes and devices should depend on evaluation of the nature and quality of the particular water to be treated, seasonal variations, the desired quality of the finished water and the mode of operation planned.

5.1 GENERAL

For the design of a new plant, the designer should use pilot plant data that has been accumulated over a period of time that at a minimum would cover winter and summer operations, and over a wide range of historically demonstrated raw water conditions (at a minimum winter and summer). Where no such data are available, treatability studies should be conducted covering the full range of water quality conditions. Care should be exercised in interpreting treatability study data since they may not provide information directly appropriate for scale-up of attributes such as reaction and retention times and filtration rates. Samples should be taken at the proposed intake location and depth to establish a data base for design. The design of the process units should become progressively more conservative as the quantity and reliability of experimental or operating data decreases. Consideration of variable surface water quality due to seasonal changes can be crucial in the selection of processes and equipment.

In some cases, design parameters may be determined by other means such as experience with similar water in other locations or literature searches, if properly documented.

When designing an expansion of an existing water treatment plant, the designer should determine the treatment needs for the specific raw water source, as described in *Section 4.1 – General*, based on operating data accumulated over a substantial period of time (i.e., at least three years). Where a particular water quality parameter is the principal factor in treatment design, sufficient data should be gathered for proper statistical analysis.

The designer should consider water quality and regulatory requirements together with the following site specific treatment considerations:

- Pathogen removal/inactivation;
- Control of ***disinfection by-products*** (DBP);

- Control of health-related parameters;
- Control of aesthetic parameters;
- Flexibility to respond to 'emerging' or newly identified and detectably present contaminants;
- Potential for accelerated corrosion or scale formation; and
- Readily available biological nutrient levels in the treated water.

Other considerations include operability, reliability, flexibility for expansion, site limitations, social considerations (impact on neighbours and surrounding area), minimizing the impact to the natural environment and economics (both capital and operation/maintenance costs).

5.1.1 Blending of Dissimilar Waters/ Treatment Changes

If a new water supply source is brought into service with the existing supply, it is possible to create water quality problems when the dissimilar waters are blended within the distribution system. Likewise, changes to treatment and/or disinfection that alter the chemical characteristics of the treated water may also have an adverse impact on the distribution system and household plumbing. For example, if surface water with higher dissolved oxygen levels is blended with ground water, iron or manganese can be precipitated. Another potential impact is increased corrosivity in the zone served by the new/ changed source of water supply. The designer should consider the potential water quality impacts of adding a new source or changing the existing one and provide additional/ modified treatment if necessary.

5.2 PRE-ENGINEERED WATER TREATMENT COMPONENTS

Pre-engineered water treatment components are normally modular process units which are pre-designed for specific process applications and flows. Multiple units may be installed in parallel to accommodate larger flows.

Pre-engineered treatment components are especially applicable for small systems where individually engineered treatment plants may not be cost effective. Factors to be considered when selecting a pre-engineered water treatment component include:

- Demonstration of treatment train/unit process effectiveness under all raw water conditions and system flow demands, especially for winter conditions and northern waters;

- Means to optimize treatment and the flexibility to handle the process residuals generated;

- Sophistication of equipment and the reliability and experience record of the proposed treatment equipment and controls;

- Operational oversight that is necessary (i.e., full time operators or automation plan);

- Formal commissioning, start-up and follow-up training, operations and maintenance manuals and troubleshooting available from the manufacturer or contractor;

- Manufacturer warranty, replacement guarantee and confirmation of meeting performance objectives;

- Timely availability of parts and service; and

- Estimated annual operating and maintenance costs.

Pre-engineered treatment components require significant engineering and integration with other components, such as chemical feed and storage systems, building, electrical and plumbing systems, as well as instrumentation and controls.

5.3 SCREENING

Raw water screens should be provided for removal of large solids, with the screen mesh size and materials of construction consistent with the raw water quality. A screen mesh size of 10 mm (0.4 in) is common (a smaller size is typically required for membrane applications). The screen should be sized for a maximum velocity of water through the screen of 0.6 m/s (2 ft/s) regardless of water level in the screen well. Where parallel screens are used, the maximum velocity with one screen out of service should not exceed 0.9 m/s (3 ft/s).

A minimum of two screens should be provided. Depending on the size of the plant, the design may consider provision of either two fixed screens in series, two rotating mechanical screens in parallel, or one rotating screen plus one fixed screen in series. In each case, the designer should ensure that sufficient space exists above the screen to permit removal.

Fixed screens should have suitable lifting lugs on the screen, and a lifting hook or beam positioned above the screen to assist in removing it. When it is intended that screens be cleaned manually, the designer should pay particular attention to the size of screen sections and materials of construction to ensure that screen removal and handling can be readily accomplished.

Rotating screens should have either automatic or manual advance mechanisms arranged so that complete washing of the screen is accomplished. Head-loss metering equipment should be installed to monitor and react to excessive head loss, and for automatic systems, trigger cleaning. The screen rotation should be such that even wear is obtained from all sections.

For either type of screen, washing facilities should be provided using high pressure water through an appropriately sized line. Screen washings should be diverted to a holding tank, preferably with a basket type screen, so that screen wastes can be simply dewatered prior to adequate disposal. Screen wastes should not be returned to the raw water well.

Where micro-screens are provided for removal of algae, larger pore size pre-screens should be provided to protect the mesh of the micro-screens.

Screen wells should be of watertight design with provision made either through valving or stop logs for isolation of the well for cleaning or inspection. Where there are multiple screen wells, means for isolation of these wells for maintenance purposes should be provided to ensure continued operation of the plant. The screen well should be covered with a curb around any floor openings to prevent water running from the floor into the well. Wells should be provided with differential level indicating devices to permit the headloss across the screen to be determined to assess the need for cleaning.

The designer should be aware of the potential of frazil ice formation and plugging of screens with a shallow depth of intake. Protection from this may best be achieved by installation of a boom enclosing the area over the intake to accelerate ice cover formation. The provision for back flow and/or local heating may also be considered. Refer to *Section 4.2 – Surface Water* for information regarding the design of intake facilities.

5.4 COAGULATION & FLOCCULATION

5.4.1 General

The effective removal of colloidal/micron-sized particles using granular media depth filters requires chemical destabilization of suspended particles so they will agglomerate into settling floc or adhere to the media. Design considerations for coagulation and flocculation processes include: the type, concentration and dosage range of coagulants, ***coagulant aids*** or flocculant aids; rapid mixing of the chemicals into the water; flocculation methods, intensities and time; and downstream processes.

5.4.2 Rapid Mixing / Coagulation

The design objective of the rapid mix/coagulation step is to provide high intensity mixing to thoroughly distribute the coagulant chemical in advance of the hydrolysis reaction that takes only seconds to complete. Coagulation may be achieved either in a separate process tank or by the use of an in-line mixer. The detention period in the mixing zone should be minimized and limited to no more than thirty seconds.

Static mixing devices can be used to provide effective mixing only where the flow is constant and close to the design maximum of the mixer. When selecting a static mixer, the designer should take into consideration that minor reductions in flow rate through these mixers can result in significant reductions in the mixing power delivered. This may reduce the flexibility to operate treatment effectively at reduced throughput. Power mixers are preferred where flow is expected to vary. The designer should ensure easy access for maintenance and replacement of the rotating seal of power mixers.

Chemical diffusers are a component of all rapid mixing systems. The designer should be aware that solids-forming reactions that may plug the diffuser can occur and should make appropriate provisions for removal and cleaning.

Typically, a rapid mixer with a mixing intensity ***velocity gradient*** (G value) in the order of 1000 s^{-1} is effective. Adding coagulants to raw water wells and allowing pumping units to perform the mixing process is not recommended. Where alkalinity or pH adjusting chemicals, powdered activated carbon (PAC) or potassium permanganate use is anticipated, addition of these should take place 3 to 5 minutes upstream of coagulant addition.

5.4.3 Flocculation

Following coagulation, flocculation is used to enhance the collisions of destabilized colloidal particles and their enmeshment into settleable and filterable floc sizes. Polymer flocculation aids and activated silica should not be subjected to high shear mixing. Provisions should be made for separate addition downstream of coagulant mixing. A delay period of 3 to 5 minutes is recommended. The mixing should be thorough enough to provide opportunities for the particles to collide but also gentle enough to prevent the flocculated particles from breaking apart.

Required detention time for adequate flocculation is variable depending on water temperature and the type of downstream processes. When sedimentation is included, detention times of 25 to 30 minutes are usually sufficient in summer. When water temperatures are <5°C (<4!°F), floc formation is slower and longer detention times of 30 to 40 minutes or longer may be needed. For direct filtration, the detention time required is usually less, typically 15 minutes. Even shorter times may be adequate for coagulation/flocculation for membrane filtration. However, if the flocculation time prior to membrane filtration is too short, or control of pH, alkalinity and buffering capacity of the water is inadequate when using aluminum based coagulants, dissolved aluminum concentrations in the ***permeate*** may exceed the Ontario operational guideline and/or may prematurely foul the membrane.

Typically, G values of 10 to 70 s^{-1} are needed for successful flocculation. Tapered flocculation (reducing G in each stage) is desirable, typically designed as three or four sequential process tanks. Lower velocity gradients are required for the more fragile colour floc than for flocculated suspended material (turbidity). Higher velocity gradients are needed for direct filtration to produce denser pin-point floc.

Optimum G and ***Gt*** (incorporating the time that the mixing intensity is applied) values are best determined by pilot studies. Jar testing does not always involve back-mixing which is typical for flocculation processes and is therefore a limited guide for full scale design.

To permit flexibility of operation and for maintenance purposes, two separate flocculation tanks should be provided as a minimum. To prevent short-circuiting, each tank should be divided into at least two stages. The design of the basin inlet and outlet should consider short-circuiting and shearing of floc. A drain and/or pumps should be provided to handle dewatering and cleaning. A superstructure (i.e. cover or enclosure) over the flocculation basins is needed.

Mixing may be provided either mechanically or hydraulically, provided that sufficient flexibility of operation is possible, and that G values can be varied to allow for optimization of the process. Where mechanical agitation is provided, submerged bearings are not recommended, and all submerged parts should have sufficient corrosion resistance to withstand long term use with coagulated water.

Flocculation and sedimentation basins should be as close together as possible. The velocity of flocculated water through pipes or conduits to settling basins should not be less than 0.15 m/s (0.5 ft/s) or greater than 0.6 m/s (2 ft/s). Flocculated water should never be pumped between the flocculation and sedimentation units as this will break floc. The designer of pipes and conduits should minimize changes of direction in order to avoid turbulence.

5.5 CLARIFICATION

5.5.1 General

The design objective of the clarification process is to reduce the settleable solids loading on subsequent filtration processes. A minimum of two clarifier/sedimentation tanks is recommended. Where only one sedimentation tank is provided, sufficient finished water storage should be provided to allow continuous water supply while the clarifier/settling tank is out of service. Alternatively, provision should be made to produce water without clarification during tank cleaning periods. It is recommended that a by-pass pipe or conduit be provided.

Clarification processes can be categorized into general types: horizontal flow sedimentation basins, upflow reactor and sludge blanket clarifiers, adsorption clarifiers, dissolved air floatation and ballasted sand or high-rate microsand process. High rate settlers are modified sedimentation tanks or clarifiers with plate or tube modules placed into the basin to increase the settling area and reduce the distance flocs have to fall.

The primary design parameter is the surface overflow rate. The type of clarification process, the performance required in terms of clarified water suspended solids, generally measured as turbidity, the type of flocculated material generated prior to clarification and the temperature of the water all dictate the optimum overflow rate.

A superstructure (i.e. cover or enclosure) over the tanks is needed. If there is no mechanical equipment in the tanks and provisions are included for adequate monitoring under all expected weather conditions, a cover may be adequate. Roof drainage should be provided and should not discharge into the tank. The designer should allow for the possibility of ice formation within settling tanks which could fall and cause damage to submerged tubes or other components within the tank if the water level is dropped. Corrosion-resistant materials should be used for tanks, piping and appurtenances.

Inlets and outlets should be designed to ensure that water is distributed evenly across the clarifier/settling tank at uniform velocities to minimize short-circuiting. In selecting the sludge collection system, the designer should consider site-specific weather conditions (potential for ice formation), the nature and quantity of suspended solids in the raw water, the type of coagulant(s) used, the shape of the tanks and provision for installation of high-rate settlers.

Drainage systems should allow the tank to empty within a reasonable time (e.g., 8 hours).

Safety of the employees must be considered in the design of tanks. As a minimum, the design should conform to Ontario Ministry of Labour requirements, other applicable laws and regulations of the Province and local municipal building department requirements. Confined space entry requirements should be considered. Ladders, ladder guards, railings, handholds and entrance hatches should be provided where applicable. The design should incorporate easily accessible fall arrest systems for use by employees or emergency response workers. Openings into tanks should be curbed and covers should have a locking device. Additional, appropriately sealable, small openings into the tanks may be appropriate for venting, testing purposes such as dye tests for short circuit detection, or observation of settling characteristics.

5.5.2 Horizontal Flow Basins (Sedimentation/ Settling Tanks)

Typically, surface overflow rates (SORs) for sedimentation tanks are from <1.0 to 2.4 m/h (<0.4 to 1.0 USgpm/ft^2). Low rates are normally needed for colour removal and high rates are suitable for turbidity removal. Where water temperatures are consistently lower than 10°C (50°F), SORs should be toward the lower end of the range. For plant capacities less than 10,000 m^3/d, where sedimentation efficiencies are frequently lower than in larger plants, SORs may need to be reduced by 15 to 25% to achieve the desired results on a regular basis. The designer should also consider the following parameters:

- Water depth of 3 to 4.5 m (10 to 15 ft);
- Mean flow velocity of 0.3 to 1.1 m/min (1 to 3.6 ft/min);
- Length to width ratio – minimum 4:1;
- Water depth to length ratio – minimum 1:15; and
- Weir loading 9 to 13 m^3/(m·h) (12 to 18 USgpm/ft).

Maximum entrance velocities should not exceed 0.6 m/s (2 ft/s). Fixed or adjustable baffles should be provided as necessary to achieve the maximum potential for settling. In evaluating different inlet baffling methods or hydraulic scale model studies, the designer should ensure that the maximum number of ports is provided, that the ports uniformly distribute flow across the baffle wall and that the headloss through the ports allows for equalization of flow distribution across the entire cross section of the tank inlet with minimum floc breakage. The water exiting the settling tank should be uniformly collected across an area that is perpendicular to the flow direction either by a submerged pipe or across a weir.

The velocity of the flow into the submerged pipe or across a weir will depend on the individual design. The use of submerged orifices is recommended in order to provide a volume above the orifices for storage when there are fluctuations in flow. Submerged orifices should not be located more than 1m (3 ft) below the water level. Where submerged outlets are used, each tank should be provided with a suitably sized overflow or other means to prevent flooding. Any overflow should be located so as to be readily visible.

Sludge collection systems should ensure full tank coverage. Where it is proposed to remove sludge manually, the tank bottom should be sloped, typically 1:100, toward the inlet end. Flushing lines or hydrants should be provided and should be equipped with appropriate backflow prevention devices. For sludge removal by travelling siphon or scraping mechanisms, the tank bottom should be flat. Where sludge is to be removed by pumping from sludge hoppers, the hopper design should be consistent with the flow characteristics of the sludge produced.

Sludge draw-off methods should take into account that sludge loadings near the tank inlet may be substantially higher than at other locations. Sludge withdrawal piping should be designed so that material withdrawn can be observed to ensure that sludge rather than settled water is being removed. Sludge pipes should be not less than 75 mm (3 in) in diameter and arranged to facilitate cleaning. The entrance to sludge withdrawal piping should be designed to prevent clogging. Valves should be located outside the tank for accessibility. All valve operators which are not within buildings should be tamper proof with provision for locking.

5.5.3 Solids Contact, Upflow Sludge Blanket & Reactor Clarifiers

Solids contact, upflow and reactor clarifiers are proprietary settling units that have their basic sizes and associated equipment pre-established by the manufacturers based on flow. Solids contact, upflow sludge blanket or reactor clarifiers are most efficient where water characteristics, especially temperature, do not fluctuate rapidly, and where flow rates are effectively constant and operation is continuous. In the evaluation of proprietary settling units, the designer may consider the following factors.

Clarifiers should be designed for the maximum uniform flow rate and should be adjustable to react to gradual changes in flow and water characteristics.

Effective back-mixing devices should provide good mixing of the influent water (raw water plus coagulant) with previously formed sludge particles and prevent deposition of solids in the mixing zone. Depending on the design of the clarifier, a separate rapid mixing process to distribute the coagulant uniformly throughout the process stream upstream of the clarifier may be required.

The flocculation and mixing detention time should not be less than 30 minutes at the expected design maximum flow. If applicable, flocculation equipment should be adjustable (speed and/or pitch) and the clarifier design should provide for coagulation in a separate chamber or baffled zone within the unit.

The units should be equipped with either overflow weirs or orifices constructed so that water at the surface of the unit does not travel more than 3 m (10 ft) horizontally to the collection trough. Weirs should be adjustable, and the summed total lengths should be at least equivalent to the perimeter of the tank. Weir or orifice loading rates will depend on the individual design of the clarifiers. Either should produce uniform rise rates for the entire area of the tank.

Surface overflow rates range from 1.2 to 6.0 m/h (0.5 to 2.5 USgpm/ft^2), depending on the design of the clarifier and the water being treated. The high rates are for clarifiers which include plate or tube settlers. Low rates are normally needed for colour removal and higher rates are suitable for turbidity removal.

Recirculation impellers should have an adjustable speed ratio of 1 to 4. Rake speed should be variable from 0.3 to 4.0 m/min (1 to 13 ft/min). Where the proposed operation is "stop-start" mode, the design should allow sludge recirculation to continue when raw water flow stops to prevent process upsets of sludge recirculation type clarifiers. The raw water inlet valve should be of the slow opening type operating over not less than one minute to prevent disruption of the floc blanket.

Sludge removal design should include:

- Sludge pipes greater than or equal to 75 mm (3 in) in diameter and arranged to facilitate cleaning;
- An entrance to sludge withdrawal piping that prevents clogging;
- Valves located outside the tank for accessibility; and
- Observation, sludge density monitoring, sampling and control of sludge being withdrawn from the unit.

Either internal or external concentrators should be provided in order to obtain a concentrated sludge with a minimum of wastewater. Typically, total water losses should not exceed 5%. Solids concentration of sludge bled to waste should be ≥3% by weight.

Discharge from blow-off outlets and drains should be treated as wastewater. Cross-connection control should be included for the drinking water lines used to backflush sludge lines.

Clarifiers should be covered either by locating them within the plant or by the use of a separate cover with personnel access to permit visual inspection of the treatment. Where open top clarifiers are proposed, the equipment should be properly weatherproofed and the rake mechanisms should be equipped with torque switches to prevent overloading. Ice blockage of effluent launder orifices may occur unless these orifices are sufficiently covered to remain ice-free, thus increasing the operating depth of the clarifier.

5.5.4 Tube or Plate Settlers

Tube or plate settlers should be inclined at an angle of 55 to 60°. Settling tanks with tube or inclined plate settler units should be designed to ensure uniform flow distribution into an entire unit, to minimize short-circuiting and to maintain velocities suitable for settling within the unit [an average velocity of 0.15 to 0.2 m/min (0.5 to 0.7 ft/min) is normally used for settling alum floc]. An approaching flow velocity of approximately 0.6 m/min (2 ft/min) should be used in the settling tank upstream of the tube or plate settler unit. SORs for tanks with tube/inclined plate settlers range from 2.5 to 5.0 m/h (1.0 to 2.0 USgpm/ft^2) where the effective settling area is the footprint area (i.e., before the plates or tubes are installed).

The designer of high rate settlers units should consider the following: settling velocity and characteristics of the suspended solids; flow velocity within the settler unit; surface loading; selection of the appropriate sludge removal equipment to be installed underneath the settler unit; spacing of launders to be installed above the settler unit with weir loadings of 3.7 to 7.5 m^3/m·h (5 to10 USgpm/ft).

Provisions should be made for cleaning and/or removal of plates or tubes and sludge removal. Flushing lines should be provided to facilitate maintenance and should be properly protected against backflow or backsiphonage. Drain piping from the settler units should be sized to facilitate a quick flush of the settler units and to prevent flooding.

5.5.5 Dissolved Air Flotation

Dissolved air flotation (DAF) offers special advantages with high colour, low turbidity raw water, or water with high algae content which causes floc to settle very slowly or to float upwards. The retention time and loading rates for dissolved air flotation units depends largely on the water being treated, the nature of the contaminant being removed, the chemicals used and the design of the DAF process. Traditional loading rates have been in the 10 to 12 m/h (4 to 5 USgpm/ft^2) range; however, higher loading rates, up to 29 m/h (12 USgpm/ft^2) may be used if confirmed through appropriate pilot testing.

The tank length should be no greater than 12 m (39 ft) to control the density of the bubble blanket. Tank depth should be 1.5 to 3.0 m (5 to 10 ft); greater depths are recommended for high algae loads. Flow velocities should be designed to limit scouring of the float from below. An inlet baffle should create a contact zone volume large enough to provide good floc/bubble contact time, but not so large as to encourage short circuiting. The angle of the baffle should be 60 to 90°, depending on the hydraulic loading rate.

The air saturated recycle flow should be adjustable and introduced at a location which ensures even distribution of the released air at the tank influent. The recycle ratio should be between 5 and 12% of inlet flow. The air flow should also be adjustable and the air injection designed to ensure an even distribution of air across the inlet baffle. Bubble diameter should be between 10 and 100μm. Saturation pressure should be 415 to 725 kPa (60 to 105 psi).

The DAF effluent (subnatant) should be removed from a submerged location near the basin floor, usually by way of an underflow baffle or perforated pipe laterals. The float- sludge may be removed hydraulically or mechanically. In selecting the float-sludge removal system, the residuals handling system should be considered.

The designer may consider the use of DAF on a seasonal basis (e.g., for algal blooms).

5.5.6 Ballasted Flocculation & Clarification

This is a proprietary treatment system which operates in up-flow mode and uses microsand-enhanced flocculation and lamellar settling for clarification. The process may allow very high loading rates, and therefore a smaller footprint, in comparison to conventional flocculation and sedimentation. Typical hydraulic loading rates are 35 to 73 m/h (14 to 30 USgpm/ft^2). This process may need a specific combination of chemicals for effective treatment depending on a raw water quality. A means to recycle and clean the sand ballast for reuse in the process should be provided. The designer may consider this process, particularly for situations where the site area is limited, for the clarification process in the main treatment train or where backwash water is to be clarified before recycling (*Section 11.2.3 – Membrane Filtration*).

5.5.7 Roughing Filters

Roughing filters are an alternative clarification process which may be operated in either up-flow or down-flow mode. They create a zone of laminar flow and suspended particulate deposits on the filter media. To clean the filter, the media is agitated to loosen the solids, or in the case of upstream roughing filters, is such that the flow can be controlled to allow water to flow backwards (down) through the filters. Roughing filters are frequently used upstream of slow sand filters when the source water requires pre-treatment to remove coarse particles that could lead to unacceptable rates of headloss development.

5.5.8 Adsorption Clarifiers

Adsorption clarifiers operate on the principle of granular media flocculation. The flocculation and clarification process takes place as the coagulated water travels upwards through a buoyant plastic media. Flocculated solids are trapped in the media. These systems are proprietary and use a combination of hydraulic flocculation, roughing filtration and rapid rate filtration. SORs are in the range of 19.5 to 25.5 m/h (8 to 10 USgpm/ft^2). Air scour should be provided for cleaning the filters. Pilot testing is recommended for site specific applications.

5.6 GRANULAR MEDIA DEPTH FILTRATION

5.6.1 General

The designer should evaluate the following interrelated factors when designing a granular media filtration process: the requirements of the filtered water quality specified in the *Procedure for Disinfection of Drinking Water in Ontario* (Disinfection Procedure); site specific conditions including raw water quality; pre-treatment process(es) and associated chemical application points; plant size/capacity; materials of construction; type of filtration technology; filtration rate; control of filtration rate; type of filter bed including the media size, thickness of media layers, and number of independent filters; available headloss for filtration; type of media support and underdrain; type of filter wash system; and filter-to-waste. Treatment and/or disposal of waste residuals should also be considered in the selection and design of the filtration process.

The number of filters/filter trains provided should depend on the process selected; i.e., with or without prior clarification, the method of plant operation, the method of filter control and the quantity of available storage.

At least two filters should be provided, each capable of independent operation and backwashing. Where only two units are provided, the filters should be capable of meeting the plant gross design capacity at the design filtration rate and, for security of supply, consideration should be given to having additional filter area so that each filter is capable of meeting the majority of plant gross design capacity at the design filtration rate.

Where more than two filter units are provided, the filters should be capable of meeting the plant gross design capacity at the design filtration rate and each filter should be capable of independent operation and backwashing.

To avoid the potential for turbidity breakthrough, the designer should select an adequate number of filters and area of each filter bed so the filtration rate can remain the same or not increase substantially (less than 10% gradual change in hydraulic loading) during the backwashing of filters.

The filtration rate and terminal head loss for a particular type of filter and filtration medium design should be selected considering total required area of the filter bed, the available hydraulic loss during filtration, the anticipated terminal head loss prior to turbidity breakthrough in the filter bed and the anticipated filter run.

All filters should be equipped as follows:

- Means for obtaining influent and effluent samples;
- Indicating flow meter and flow control to each filter/filter train;
- Continuous effluent turbidity measuring and recording device; particle monitoring equipment may be useful in enhancing overall treatment operations;
- Indicating loss of head gauge;
- Provisions for filtering-to-waste with appropriate measures for backflow prevention or operational procedures to achieve the same water quality results;
- Wall sleeves providing access to the filter interior at several locations for sampling or pressure sensing or equivalent other devices; and
- Pressure hose [25 to 37 mm (1 to 1.5 in)] and storage rack at the operating floor for washing filter walls (gravity filters).

The filter structure should be designed to provide for:

- Vertical walls within the filter;
- No protrusion of the filter walls into the filter media;
- Cover or enclosure by superstructure;
- Head room to permit normal inspection and operation;
- Minimum depth of filter box of 2.5 m (8.2 ft);
- Minimum water depth over the surface of the filter media of 1 m (3 ft) [1.5m (5 ft) for high rate filtration] to prevent air binding due to dissolved air coming out of solution in the filter bed;
- Effluent piping designed to prevent backflow of water and air to the bottom of the filters and to provide minimum operating conditions for flow meters;
- Prevention of floor drainage to filters with a minimum 100 mm (4 in) curb around the filters;
- Prevention of flooding by providing overflow;
- Maximum velocity of treated water in pipe and conduits to filters of 0.6 m/s (2 ft/s);
- Cleanouts and straight alignment for influent pipes or conduits where solids loading is heavy or following lime-soda softening;
- Washwater drain capacity to carry maximum backwash flow;
- Walkways around filters, to be not less than 600 mm (24 in) wide;
- Safety handrails or walls around all filter walkways; and
- Construction to prevent cross-connections and common walls between potable and non-potable water.

Washwater troughs should be constructed to have:

- The bottom elevation above the maximum level of expanded media during washing;
- A 50 mm (2 in) freeboard at the maximum rate of wash;

- The top edge level all at the same elevation (adjustable weirs are recommended);
- Spacing so that each trough serves the same filter area;
- A horizontal travel distance for suspended particles to reach the trough of 1 m (3 ft) for sand media; and
- Trough spacing of 1.8 to 3m (6 to 10 ft) for dual media with anthracite or granular activated carbon (GAC).

The designer should refer to the Disinfection Procedure for more information on the design, operation criteria and performance requirements of specific types of granular media filtration processes and applicable pathogen removal credits.

The design should include provision for modifications of the filters or the addition of more filters so that future construction will have minimal impact on water treatment plant operations.

5.6.1.1 Flow Control

Flow control can be designed using different strategies; however, the system should control the flow to each individual filter, apportion the total flow among the individual filters and accommodate rising head loss through each individual filter run. The designer should consider cost, complexity and reliability when selecting a control strategy.

There are two basic modes of filtration control:

- Constant rate filtration; and
- Declining rate filtration.

In constant rate filtration, the flow to each filter should be maintained at as constant a rate as possible with clearwell storage absorbing fluctuations in demand and in filter output (i.e., when a filter is taken out of service for backwashing). This is typically accomplished by a flow meter and a flow modulation valve on each filter effluent pipe, or constant level filtration with equal flow splitting inlet weirs, a water level sensor and a flow modulator valve.

5.6.1.2 Filter Media

Filter media should conform to NSF/ANSI Standard 61: Drinking Water System Components - Health Effects and the applicable AWWA Standard

B100: Filtering Material or AWWA Standard B604: Granular Activated Carbon. When GAC is used, provisions should be made for periodic replacement or regeneration.

The selection of media type, size (effective particle size and uniformity coefficient), distribution, depth and L/d ratio (L=depth, d=filter media effective particle size) should be such that, in operation, the filter reaches its design terminal headloss at approximately the same time as either turbidity or colour breakthrough occurs, based on whichever is the controlling process parameter. The media selection also depends on the concentration and type of suspended solids to be removed by the filter.

For traditional dual media filter designs, the media should consist of a lower level of silica sand, not less than 200 mm (8 in) deep, and an upper layer of anthracite coal or GAC not less than 450 mm (18 in) deep. The designer should be aware that direct filtration is more sensitive to variations in media selection. The media selection should ensure fluidization of each layer of media during backwashing and subsequent re-stratification of the media.

In addition, some types of filter bottom/underdrain systems require supporting media to prevent the passage of filter media through the filter bottom. Typically, gravel support layers in three or four overlapping gradations should be provided. The smallest size is usually in the 2 to 5 mm (0.08 to 0.2 in) range; the largest size and the depth of the layers will depend on the type of filter bottom used. Other media support methods (gravel-less systems) are also available.

Alternate configurations, including multi-media, coarse deep beds and proprietary media designs, should be pilot tested to ensure their suitability, or have appropriate documentation of past performance.

5.6.1.3 Underdrains

The most important functions of the filter bottom or underdrain are to provide an even rate of filtration over the entire area of the filter and uniform distribution of backwash water and/or scouring air. The filter bottom should be designed so that all head losses on backwashing occur at the final openings to ensure an even distribution of washwater.

Porous plate underdrains should not be used where iron or manganese may clog them, with waters softened by lime or with water susceptible to algae growth or biofouling.

5.6.2 Rapid Rate Gravity Filters

The use of rapid rate gravity filters requires pre-treatment (chemically assisted filtration). Filters should be designed to achieve an individual filter effluent turbidity of <0.1 NTU, other than during the ripening period when the effluent should be controlled.

The rate of filtration should be determined through consideration of such factors as raw water quality, degree of pre-treatment provided, filter media type(s), specifications and depths, and the competency of operating personnel. For traditional dual media filter designs, a maximum filtration rate of 11.7 m/h (4.8 USgpm/ft^2) is recommended, although filter rates of up to 20 m/h (8.1 USgpm/ft^2) have successfully been achieved. Filtration rates of 11.7 m/h (4.8 USgpm/ft^2) may not be achievable with floc formed from high colour water. For all filter designs, filtration rates greater than 11.7 m/h (4.8 USgpm/ft^2) should be confirmed through pilot testing. Pilot testing in cold water conditions is also advisable to establish acceptable rates.

5.6.2.1 Backwash Systems

A sufficient volume of water should be available for backwashing all filters every 24 hours. The backwash rate should be variable, with the maximum rate designed to provide 50% expansion of the filter media bed at the highest water temperature. Generally, the rate needed for this expansion is 37 to 50 m/h (15 to 20 USgpm/ft^2). Lower backwash rates are required in GAC filters or contactors, since GAC is less dense than anthracite.

Lower backwash rates are also needed to fluidize the bed at the beginning of the wash and to allow the media to re-stratify at the end of the wash. The design should allow for a backwash duration of at least 15 minutes. An effective backwash of a filter is required before return to service and may require more than 15 minutes depending on conditions. For filters with air scour, a lower maximum wash rate and a shorter duration may be sufficient.

Filtered water should be used for backwashing and provided at the required rate by a minimum of two washwater pumps (one duty and one standby). The use of high pressure sources with pressure reducing valves is not recommended as failure of pressure reducing valves may disrupt filter media which would then need to be re-stratified.

A flow regulator, flow meter and flow indicator should be provided on the main backwash header. An air release valve should be placed at the high point of the header. The system should be designed so that rapid changes in backwash water flow do not occur.

Backwashes should be operator initiated; or alternatively, automated systems should be operator adjustable.

5.6.2.2 Supplementary Wash & Air Scour

A supplementary surface/subsurface wash system or air scour should be provided. A supplementary wash could be either a system of fixed nozzles or a revolving-type apparatus. All such systems should be designed with:

- Provision for water pressures of at least 310 kPa (45 psi) or as specified by the manufacturer;
- Backflow prevention to prevent backsiphonage if connected to the treated water system; and
- Flow of 4.9 m/h (2.0 USgpm/ft^2) with fixed nozzles or 1.2 m/h (0.5 USgpm/ft^2) with revolving arms or as specified by the manufacturer.

Air flow for air scouring the filter prior to backwashing should be 0.9 to 1.5 m^3/(min·m^2) (3 to 5 ft^3/min·ft^2) of filter area when the air is introduced into the underdrain. A lower air rate should be used when the air scour distribution system is placed above the underdrains. The air should be free from contamination. Oil-free compressors should be used. Air scouring should be followed by a fluidization wash sufficient to restratify the media.

Air scour distribution systems should be placed below the media and supporting bed interface; alternatively, if placed at the interface, the air scour nozzles should be designed to prevent media from clogging the nozzles or entering the air distribution system. Air scour systems or nozzles should provide for even air distribution. Piping for the air distribution system should not be flexible hose which will collapse when not under air pressure and should not be a soft material which may erode at the orifice opening with the passage of air at high velocity.

Air delivery piping should not pass down through the filter media nor should there be any arrangement in the filter design which would allow short circuiting between the applied unfiltered water and the filtered water. Consideration should be given in the design to maintenance and replacement of air delivery piping.

5.6.3 Direct Filtration

For surface water treatment plants using chemically assisted granular media filtration, the designer may consider omitting the clarification process where raw water average turbidity is about 5 NTU and does not exceed 20 NTU during storm excursions, colour is below 40 TCU, and algae is below 2,000

areal standard units (ASU). This decision should be based on a risk analysis in consideration of the multiple barrier approach (*Section 3.2.2 – Risk and the Multi-Barrier Approach*) and an economic evaluation of the process with and without clarification. A clarification process provides a partial pathogen barrier and enhances the overall disinfection efficiency and stability of the treatment train by allowing extra time for treatment process adjustment and control.

Coagulant aided pre-filtration solids removal using roughing or coarse media filters can extend the application of direct filtration to a slightly broader range of source waters.

5.6.4 Rapid Rate Pressure Filters

Pressure filtration with chemically assisted coagulation and flocculation (in-line pressure filtration systems) is recognized as 'direct filtration' for disinfection removal credits as described in the Disinfection Procedure. It should only be considered for low colour raw water with turbidity not exceeding 20 NTU and where incoming water quality is very consistent and rapidly forms a robust floc in cold conditions.

Pressure filtration systems usually include coagulant (and polymer or coagulant aid) injection in the pipe under pressure, a static mixer, a pressure vessel with or without large grain media where flocculation occurs, followed by rapid rate pressure filters.

Pilot testing should be conducted covering periods of low and high temperature as well as periods of high and low turbidity and colour (high colour is often the cause of system failures). The pilot study should use the allowable flow and its variations, a site specific travel time from coagulant injection point to flocculation (flocculation beyond that vessel may result in failure of the sand media filter), type of coagulant and polymer and the need for automatic coagulant dose in proportion to the turbidity and flow, where applicable.

Recommendations relative to filter media provided for rapid rate gravity filters such as rate of filtration, and structural details and hydraulics also apply to pressure filters where appropriate.

The filters should be designed to provide:

- Pressure gauges on the inlet and outlet pipes of each filter;
- Flow indicators on each filter;

- Backwash flow indicators and controls that are easily readable while operating the control valves;
- Air release valve on the highest point of each filter;
- Access hatches to facilitate inspection and repairs for filters 900 mm (36 in) or more in diameter, or handholds for smaller filters; and
- Cross-connection control.

5.6.5 Slow Sand Filtration

Slow rate gravity filtration should be limited to source water (or influent water after pre-treatment) having a maximum turbidity of 10 NTU (the turbidity should not be attributable to colloidal clay), maximum colour of 15 TCU and low algae counts. Where dissolved organic carbon (DOC) in the influent water is greater than 10 mg/L, pilot testing is essential.

Modified or enhanced slow sand filtration systems use additional pre-treatment processes prior to the slow sand filter. The water quality limitations outlined above describe the water being applied to the slow sand component of the process. Water quality limitations for raw source water prior to pre-treatment will depend on the pre-treatment processes employed.

Where organic material in the raw water is not easily biodegradable, the application of ozone (up to 1 mg/L) upstream of the slow sand filter can promote biological activity by making the natural organic matter (NOM) in the water more amenable to biological removal. It coincidentally increases dissolved oxygen, which is beneficial to microbial activity. Additional information is provided in *Section 5.8.2 – Biological Filters*.

Slow sand filtration rates are generally in the 0.04 to 0.4 m/h range (0.02 to 0.16 USgpm/ft^2). The design rate of filtration should be determined by pilot testing of the water to be treated.

Each filter unit should be equipped with a main drain and an adequate number of evenly spaced lateral underdrains to collect the filtered water. The underdrains should be so spaced that the maximum velocity of the water flow in the underdrain will not exceed 0.23 m/s (0.75 ft/s). The maximum spacing of laterals should not exceed 1 m (3 ft) if pipe laterals are used.

Media depths should typically be in the 0.75 to 1.5 m (2.5 to 5 ft) range. The effective particle size should be between 0.15 mm (0.006 in) and 0.30 mm (0.012 in) and the uniformity coefficient should not exceed 2.5. The supporting gravel should be similar to the size and depth distribution provided for rapid rate gravity filters.

The filter design should maintain a depth of water of 1.8 to 2.1 m (6 to 7 ft) above the sand. Influent water should not scour the sand surface. Each filter should be equipped with an indicating loss of head gauge for confirming active biological filtration.

Slow rate filters should be designed to provide:

- Means for cleaning and/or scraping of sand;
- A cover with headroom to permit normal movement by operating personnel for scraping and sand removal operations, and to prevent exposure to sunlight;
- Adequate access hatches and ports for handling of sand and for ventilation;
- Filter-to-waste (a minimum two days flow should be considered);
- An overflow at the maximum filter water level; and
- Protection from freezing.

5.6.6 Diatomaceous Earth Filtration

Diatomaceous earth (DE) filters can provide effective pathogen removal and can be used for polishing following other filtration processes. The use of DE filters should be limited to source water (or influent water after pre-treatment) having a maximum turbidity of 20 NTU and maximum colour 15 TCU. Filtration rates should be determined through pilot testing. The designer should refer to the Disinfection Procedure and the AWWA *Manual of Water Supply Practices M30 – Precoat Filtration* for more information on the design criteria for DE filtration processes.

5.7 STRAINING FILTRATION PROCESSES

5.7.1 General

The basic principles and design factors described in *Section 5.6 – Granular Media Depth Filtration* should be considered for designing filtration processes using other than granular media. The designer should always refer to the Disinfection Procedure for more information on the design and operation criteria of specific types of filtration processes and applicable pathogen removal credits.

5.7.2 Membrane Filtration

5.7.2.1 General

The terminology used for membrane system components and processes is not consistent among all suppliers/manufacturers. Refer to *Appendix A - Glossary* for clarification of the terms used in this section.

Membrane filtration systems are proprietary and the manufacturer should be consulted for specific design requirements. The following are general design considerations for microfiltration (MF) and ultrafiltration (UF) membrane systems most commonly used in Ontario.

Nanofiltration has not yet found wide application in Ontario, although there are some installations across Canada, primarily for organics removal. Reverse osmosis membrane systems are mainly used as point-of-entry or point-of-use systems in Ontario. Experience with nanofiltration and reverse osmosis membrane systems to date has not been sufficient to provide specific design guidelines; the designer should therefore consult the manufacturer if considering either of these systems.

5.7.2.2 General Design Considerations

The design flow rate for membrane systems is the net filtered output desired from the membrane system. The designer should take into account the loss of feed water used for backwashing and/or reject stream (waste stream) and the lost production while a unit or train is out of service for chemical cleaning. The designer should consider the capability of the source to provide enough water to allow for losses and the capacity of the disposal system to handle waste volumes while meeting system demand (*Section 3.6 – Plant Capacity Rating*).

The overall cost of the delivered water is strongly affected by membrane life. Membrane life depends on membrane fouling rates, among other factors such as oxidant exposure or transmembrane pressure. Generally the higher the design ***flux*** for a given water quality, the shorter the membrane life. This trade-off should be selected by the designer in consultation with the municipality/owner and the membrane manufacturer and included in the manufacturer performance guarantee.

Operation and useful life vary depending on type of membrane selected, quality of feed water and process operating parameters. Specific issues the designer should consider include membrane flux, water quality and temperature, cross-connection control and system reliability. It is important for the designer to test a range of different manufacturers' membranes for a given raw water source as substantially different and unpredictable performances may occur.

For most raw water sources either pressure or submerged (vacuum) type membrane systems can provide satisfactory performance. A factor that may influence the choice between vacuum and pressure systems is the performance of the system during pilot testing. In currently available equipment, submerged systems tend to accommodate larger modules than pressure systems, and have fewer valves and piping connections. Pressurized cartridge systems in contrast are compact and more easily accessible for service and can make effective use of smaller quantities of more concentrated and potentially reusable cleaning solutions.

The ability to obtain qualified operators [in accordance with the requirements of Certification of Drinking-Water System Operators and Water Quality Analysts (O. Reg. 128/04) under the Safe Drinking Water Act, 2002] should be evaluated in selection of the treatment process. The necessary operator training and the required operator certification should be obtained prior to plant start-up.

Pilot Testing

Site specific pilot testing is usually needed to select the membrane and to determine particulate removal efficiencies, fouling potential, flux, pressures and pre-treatment requirements. The specific flux for any particular membrane is a strong but predictable function of water temperature and viscosity and will be well known to the manufacturer. Cold weather performance therefore is predictable provided organic and inorganic contaminant levels and types do not change substantially with the seasons.

Fouling potential and pre-treatment needs are site specific and can be difficult to predict without pilot testing. On occasion, it may be possible without pilot work to accurately predict membrane system performance from that of nearby plants which treat very similar quality raw water. However, the membrane fouling rate is an important design consideration that can be strongly dependent on the make up of raw water organics and is difficult to accurately characterize.

A pilot study allows the designer to determine the optimal combination of flux, pressure, ***recovery rate*** and cleaning interval. Membrane systems should be designed to operate within the specific range of pressures and fluxes of the membrane.

Membrane Flux

The sustainable flux dictates the membrane area necessary to achieve the desired system capacity. To minimize the number of modules required, and associated capital costs of the membrane filtration system, the designer should strive to maximize the membrane flux without inducing excessive fouling.

The optimum flux should be based on pilot test results. Cold water significantly reduces the flux of a membrane system; hence, cold season demand may govern the required design membrane area.

System Reliability

The designing engineer should provide a system that reliably meets the water demand and pathogen removal credits for the design period without the need for major reconstruction or refurbishment.

Scheduled membrane replacement represents a major cost component in the overall water production costs. The designer should consider that membrane replacement frequency may significantly affect the overall cost of operating the treatment facility.

Designers selecting membrane systems should be aware that this is a fast developing field of technology. Production of membrane system parts may be discontinued and other manufacturers' parts may not be compatible or interchangeable. As a result the designer should consider providing ample space for expansion and installation of alternative equipment, and inform the municipality/owner of the inherent risks.

A minimum of two independent membrane filter trains should be provided. When determining the total amount of membrane area and number of membrane trains to meet system demands, the effect of having one train off-line should be included in the plans. When a train is off-line for cleaning, the remaining trains will need to be capable of operating at a higher flux rate for the duration of the cleaning cycle in order to meet system demands. Where possible, this should be avoided as operating at high flux rates may significantly accelerate deterioration of the membrane performance.

The need for redundant trains and equipment should also be considered when selecting the number and size of trains (*Section 3.29 – Reliability and Redundancy*). The designer should consider the balance between true redundant trains and those used for balancing flow and minimizing the instantaneous peak factor of the system, which may affect the sizing and operation of upstream and downstream processes. Where a system has been designed with a fully redundant train, operational hours should be shared equally between all trains on a rotating basis.

For staged expansion of plant capacity, the appropriate infrastructure for the projected future demands should be installed, and guarantees of future replacement pricing geared to a price index, if required, together with replacement product availability assurances from the manufacturer. Stored membranes may have a limited shelf life.

Cross Connection Control
Cross connection control considerations should be incorporated into the system design, particularly with regard to chemical feeds and waste piping used for membrane cleaning, the waste stream and ***concentrate***.

5.7.2.3 Pre-Treatment

Pre-treatment may be required prior to UF and MF systems to prevent potential fouling of the membranes and/or to reduce disinfection by-product formation, particularly where raw water TOC levels are high.

The pre-treatment unit processes that may be evaluated for integration with membrane filtration systems include:

- Pre-screening of any membrane system to protect the membranes from damage by debris. The required screen size and/or strainer should be dictated by the requirements of the membrane manufacturer;

- Oxidation to be integrated with membrane processes to assist with organics [total organic carbon (TOC) and dissolved organic carbon (DOC)] and taste and odour reduction. It is recommended that the oxidation process be introduced as far upstream of the membrane process as possible. The designer should obtain concurrence for the use of a particular oxidant from the membrane manufacturer;

- Adsorption processes are normally used downstream of the membrane process for removal of organics (TOC and DOC) and taste and odour causing compounds. When carbon adsorption processes are considered upstream of membrane processes, pilot tests should be carried out for the specific membrane and carbon grade to assess the potential reduction in membrane life due to the presence of abrasive carbon fines. When biological filtration is planned upstream of membrane filtration, optimization of pilot biological filtration over a minimum period of 4 months should be conducted before commencing membrane pilot work on the biological filter effluent; and

- Coagulation upstream of the membrane process is not needed for effective pathogen removal. Coagulant use may lead to additional expense and residuals handling costs and may require conditioning of the raw water to be effective. Where coagulant is needed, for example, for colour/dissolved organic substances removal, the coagulation process will add additional solids loading and may plug the membrane pores leading to extra cleaning requirements. On occasion, however, the use of coagulant may improve the agglomeration characteristics of raw water solids leading to longer duration filter runs and reduced chemical cleaning requirements. Utilizing one of the two processes to reduce the solids loading on the membranes can improve membrane performance which could in turn lead to less membrane surface area required and extended life of the membranes. Where coagulation is needed for a substantial part of the operating year, conventional treatment should be evaluated and cost compared.

An additional factor for the designer to consider is the effect of upstream processes on the membrane system. For example, many membranes have restricted tolerance for exposure to chlorine the use of which may be needed for mussel or taste and odour control. Other processes such as biological filters and contactors can significantly affect membrane cleaning requirements and life. Many of these processes are difficult to pilot accurately. The designer should consider the applicability/reliability of pilot results and/or consider placing these processes downstream in the treatment train.

Membranes can be effective for the removal of divalent iron and/or manganese. However, the use of a rapid acting oxidant and sufficient contact time should be allowed for chemical reaction completion and some precipitate/floc formation upstream of the membrane filter.

5.7.2.4 Backwash & Chemical Cleaning

The designer should keep in mind that chemical cleaning of membranes is required at regular intervals of a few weeks or less to slow the deterioration of available flux to acceptable levels. Failure to apply cleaning chemicals in the optimum manner can lead to rapidly declining membrane performance and a need for early membrane replacement. Backwashing and chemical cleaning frequencies, durations and procedures should be obtained from the membrane manufacturer, or be determined based on pilot study data or similar application data.

The membrane should be periodically cleaned with chemicals (both ***chemically enhanced backwash*** and ***recovery clean***). Membrane cleaning chemicals may be highly aggressive and excessive cleaning may shorten effective membrane life. The membrane manufacturer should provide appropriate cleaning instructions to balance performance and performance degradation and the costs of cleaning for each specific installation. Care must be taken in the cleaning process to prevent contamination of both the raw and finished water system.

5.7.2.5 Integrity Testing

To routinely evaluate membrane and housing integrity and overall filtration performance, the designer should consider methods for periodic integrity testing. There are five key aspects for achieving an integral membrane system:

- Performance requirements;
- Type of integrity test;
- Integrity test criteria and settings;
- Frequency of integrity testing; and
- Management of the process and information.

There are two basic types of integrity testing: continuous indirect integrity testing and periodic direct integrity testing.

Indirect integrity testing includes on-line particle counting used as a continuous indication of the membrane integrity. In general, sustained particle counts in the filtrate should remain below 20 counts/mL. If filtrate particle counts exceed 20 counts/mL for an extended period of time, this may be an indication that a membrane fibre has been breached and should be isolated and checked for integrity. An alarm should be provided with continuous indirect integrity testing.

The designer should provide means for direct integrity testing, including such measures as pressure decay, vacuum hold, bubble point or sonic testing. The required frequency of direct integrity testing will depend on the quality of the influent raw water and the robustness of the membranes.

Integrity testing is a requirement if the membrane process is to be used for disinfection removal credits (refer to the Disinfection Procedure). Whatever integrity monitoring technique is adopted, it should be capable of confirming numerically that the required log disinfection credit is being achieved and that process train leaks are repaired to consistently achieve this performance.

For those systems that have to be tested on-line during production, a filter-to-waste option should be considered in the event of a membrane integrity breach.

5.7.2.6 Ancillary Equipment

The designer should specify or ensure that the membrane manufacturer contractual commitment includes the following ancillary equipment:

Feed Water or Permeate Pumps, Blowers & Compressors
Where pumps, air blowers and compressors are employed, the number of duty pumps, air blowers and compressors required will depend on the number of process trains selected and the anticipated range of flows. A standby unit should be available for any process train in the event one of the duty units is out of service for maintenance or repair. For small systems with adequate storage, the use of "shelf-spares" in place of standby units may be considered acceptable. The designer should also consider the efficiency of pumping and blower equipment, as these are energy intensive processes and operation may be continuous or semi-continuous.

Isolation Valves & Unions
Isolation valves are required for each individual membrane assembly. The size of the individual modules is such that it is often impractical to isolate individual membrane modules. Instead, isolation valves are to be provided to isolate individual trains and membrane assemblies, or subsections of the membrane assemblies.

Piping and Automated Valves
Some membrane systems operate over a wide range of pressures and have a significant number of automated valves. Select piping materials, restraints, and actuator speed controls suitable for the intended materials, service and to prevent water hammer. The designer should ensure that the valves and piping are suitable for a wet and chlorine heavy environment. Valves and actuators should be suitable for multi-cycle operation rather than modulation/shut-off only, where required.

Chemical Feed Systems
Chemical feed systems should have standby pumping units. Refer to *Chapter 6 - Chemical Application* for storage and safe handling of the chemicals.

The designer should also consult the manufacturer regarding the design of HVAC systems, the provision of means for access to, removal of and repair of membrane modules, valves and instrumentation.

5.7.2.7 Monitoring Equipment

Flow Metering Systems
Flow meters should be provided to directly or indirectly continuously monitor:

- Main raw water supply line (or individual train raw water supply lines) to measure the feedwater volume entering the membrane system and for flow pacing of any pre-treatment chemicals;

- Individual permeate lines from each membrane train to measure the filtration rate and volume of each train and pace post disinfection chemicals;
- Individual reject or concentrate lines from each train to measure the flow rate and volume of waste stream water for calculating the overall recovery rate of the train;
- Individual backwash lines (or use of the permeate flow meters) to measure the backwash flow rate and volume;
- Combined filter effluent line and/or the distribution main header leaving the plant; and
- On-line means for confirming flow paced chemical additive dosing.

On-line Metering/Monitoring Systems
An on-line turbidimeter should be provided on the common feed water line to the membrane trains.

On-line turbidimeter instruments should be provided on the permeate discharge from each membrane train. The provision of particle counters may be considered on a per train basis. Sample point connections should be provided at each rack or cassette for connection of a portable particle counter to aid in troubleshooting in the event of a fibre breakage.

Provisions should be made for pH and residual measurement, either on-line or at convenient sample points, on each membrane ***clean-in-place*** (CIP) tank to monitor the cleaning solution concentrations, typically citric acid. When protein fouling from biofilm on the membrane requires the use of protease enzyme solutions, strength measuring techniques, as recommended by the manufacturer, should be applied.

Pressure gauges and transmitters should also be provided on each membrane train to measure transmembrane pressures for monitoring the rate of fouling and to initiate chemical cleaning, and backpulse pressures to avoid over pressurization and damage to the membrane fibres.

5.7.2.8 Residuals

The ministry should be consulted, as early as possible, when considering the use of membrane technologies, to determine environmentally acceptable options for disposal of waste streams from both pilot scale and full scale membrane plants.

Neutralization of the cleaning solutions should be provided, either directly in the process tank where the CIP has taken place, or the solutions should be transferred into a holding tank to ensure sufficient time for neutralization and monitoring prior to disposal.

Disposal of reject water and waste from chemically enhanced backwashing and recovery cleaning is also discussed in *Section 11.2.3 – Membrane Filtration*.

5.7.3 Bag & Cartridge Filtration

This technology is designed to meet the low flow requirements of small systems. The use of bag or cartridge filters should be limited to source water (or pre-treated influent) having a maximum turbidity of 5 NTU and maximum colour of 5 TCU. Typically, cartridge and bag filters are used in series with decreasing pore size.

In order to claim the 2.0 log Cryptosporidium oocyst removal credit, the cartridge/bag filtration process should meet the following criteria:

- Filter elements and housing should be certified for surrogate particle removal evaluation in accordance with testing procedures and manufacturing quality control specified in NSF/ANSI *Standard 53: Drinking Water Treatment Units - Health Effects* or equivalent;
- Filtrate turbidity from each filter is monitored continuously;
- Alarming is provided if differential pressures across the filter medium exceed the manufacturer rating; and
- Materials coming in contact with water conform to NSF/ANSI *Standard 61: Drinking Water System Components - Health Effects.*

The particulate loading capacity of these filters is low, and once reached, the bag or cartridge filter should be discarded. The operational and maintenance cost of bag and cartridge replacement and disposal should be considered when designing a system.

The design flow should be determined in consultation with the manufacturer specifications and confirmed with a pilot test. The pilot testing should be carried out with the actual size of the filter element at the design maximum flux and set up so as to provide an assurance of practical filter element life. The design should consider provisions for adding chlorine or another disinfectant at the head of the treatment process to reduce or eliminate the growth of microorganisms such as algae and biofilm on the filters. The impact on disinfection by-product formation should be considered.

Any pre-treatment filters should have filter-to-waste capability or other means to prevent blinding of the bag or cartridge filter at start-up or premature breakthrough. Filter-to-waste should also be provided for the final filter(s) and a pre-determined amount of water should be discharged to waste after changing the filters. A by-pass-to-waste line is also needed during start-up after long periods of non-use, especially on groundwater systems where biofilm forming bacteria are present. It may be necessary to adopt automatic flow redirection to a second filter train and/or discharge to waste for a short period on start-up to avoid rapid plugging of filter elements.

Pressure gauges should be installed before and after the bag/cartridge filter. The designer should ensure that either a differential pressure gauge with shut down alarm is provided or that the design pump maximum pressure is below the cartridge maximum rated differential pressure. An automatic air release valve should be installed on top of the filter housing. The flow through the treatment process should be controlled with a flow control valve and the flow measured.

A slow opening and closing valve should be included upstream of the filters to reduce flow surges. Frequent start and stop operation of the bag or cartridge filter should be avoided. To avoid frequent start and stop cycles, the following options are recommended:

- Low filtration rates which will lengthen filter run times; and
- Installation of a recirculation pump that pumps treated water back to a point ahead of the bag or cartridge filter, complete with reduced pressure principle backflow preventer to ensure there is no cross-connection between the finished water and raw water.

5.8 SOLUABLE CONTAMINANT REMOVAL PROCESSES

5.8.1 Granular Activated Carbon Contactors

GAC contactors can be used for the removal of organic compounds including those producing taste and odour, disinfection by-products, trace contaminants, pesticides and DOC removal. GAC may be used in granular media filters or in separate contactor units.

Designers should be aware that although available grades of GAC can show good adsorption performance in bench testing, the adsorptive capacity of GAC will diminish rapidly over time due to background TOC loading. This should be taken into account when designing GAC contactors or replacing anthracite with GAC in filters, particularly for the removal of taste and odour compounds.

The designer should also be aware of the potential for desorption of organics originally absorbed onto the carbon due to competition by highly adsorbing organics in the influent, resulting in higher concentrations in the effluent. In addition, sloughing of biofilm in biologically active GAC beds may cause high concentrations of bacteria in the filtered water.

A GAC bed installed (capped) over existing filter beds can function as a filter by removing suspended matter but will also remove organic compounds. In most cases, GAC contactors are installed downstream of filters for taste and odour control. Where ozone pre-filtration treatment is applied, carbon contactors can provide effective removal of any remaining ozone traces and therefore protect downstream biological filtration steps.

Stand-alone GAC contactors (separate from filtration) may be gravity fed contactors, pressure contactors or upflow contactors. Gravity-fed contactors are similar to granular filters (*Section 5.6 – Granular Media Depth Filtration*) but are deeper than conventional granular filters. Pressure contactors are similar to pressure filters. The designer should consider that GAC is relatively fragile and easily crushed and subsequently will be lost as fines during backwash flow; therefore, fluidized bed contactors are not recommended.

Design factors to be considered for GAC filters or contactors include ***mass transfer zone*** (MTZ), ***empty bed contact time*** (EBCT), ***specific throughput***, ***carbon usage rate***, GAC effective particle size, uniformity coefficient and GAC bed porosity. EBCT typically ranges from 5 to 25 minutes. Typical loading rates for GAC contactors are in the range of 10 to 25 m/h (4 to 10 USgpm/ft^2). Piloting testing is strongly recommended to determine the required EBCT, the specific throughput or the loading rate with respect to site-specific raw water quality. In addition, the performance of different GACs for the removal of specific contaminants of concern should be evaluated.

For the use of activated carbon specific applications, refer to *Section 5.13 - Natural Organic Matter Control* and *Section 5.14 – Taste and Odour Control*.

5.8.2 Biological Filters

In a biological filter, the filter medium develops a microbial biofilm that assists in the removal of dissolved organic materials. Intentional biologically active filtration often includes the use of ozone as a pre-oxidant to break down natural organic materials into more easily biodegradable organic matter. Granular activated carbon filter media is often used to support denser biofilms because it has more surface area than other traditionally employed media, and may be referred to as biologically activated carbon. Biological dissolved organics removal and particle removal may occur in the same filter or in separate processes. Non-chlorinated backwash water is usually needed to preserve high levels of biological activity after backwashing. Consideration should be given to the likelihood of increased heterotrophic plate counts in the filter effluent.

The design of biologically active filters should ensure that aerobic conditions are maintained at all times. The final filter design should be based on pilot studies and should be designed as rapid rate gravity filters. Pilot studies should be of sufficient duration to stabilize the biological activity in the bed and establish the effectiveness and impact of the backwash procedures. Pressure filtration should not be used for biological filtration. Designers should be aware that carbon is electrically conductive and can strongly accelerate corrosion of exposed contacting materials.

5.9 DISINFECTION

5.9.1 General

The design of the drinking water disinfection processes must conform to the Disinfection Procedure. This Disinfection Procedure provides guidance for disinfection (***primary disinfection***), including any pre-disinfection treatment necessary to achieve the required level of removal and/or inactivation of pathogens potentially present in the source water, maintenance of a disinfectant residual in a distribution system (***secondary disinfection***) and control of disinfection by-products.

Drinking water disinfection and any pre-disinfection treatment requirements in Ontario are specific to the type of raw water supply. All water supplies should be individually assessed by measuring relevant water quality parameters. Design of the treatment processes should consider the characterization, variability and vulnerability to contamination of the raw water supply.

5.9.2 Disinfection By-Products

Disinfectants may be capable of producing disinfection by-products (DBPs) in concentrations that may present long-term health risks to drinking water consumers. The by-products produced are specific to the disinfectant and the raw water quality, and the concentrations are related to the contact time and the dosage and residual of the disinfectant.

The designer should consider alternative disinfection strategies for inclusion in the process train selected where optimized pilot or jar test filtered samples results indicate trihalomethane formation potential (THMFP) greater than the current THM standard in the *Ontario Drinking-Water Quality Standards* (O. Reg. 169/03) under the *Safe Drinking Water Act, 2002*. This test may be supplemented by simulated distribution system (SDS)-THM measurement, as specified in the most recent version of APHA/AWWA/WEF *Standard Methods for the Evaluation of Water and Wastewater*, where results of regular THMFP testing indicates that the standard may be exceeded. The potential formation of haloacetic acids (HAA) and other disinfection by-products should also be considered when evaluating disinfection alternatives.

The designer should refer to the Disinfection Procedure for design options and measures to control DBP formation.

5.9.3 Inactivation

Disinfection (primary disinfection) is a process or a series of processes intended to remove and/or inactivate human pathogens such as viruses, bacteria and protozoa that are potentially present in the water before the treated water is delivered to the first consumer.

Effective inactivation of pathogens in adequately filtered influent water, or groundwater of suitable quality, can be accomplished by either chemical or physical means such as the use of chlorine, monochloramine, chlorine dioxide, ozone or ultraviolet light. The designer should refer to the Disinfection Procedure for design options and specific requirements related to the use of different disinfection processes, the need for and use of different pre-inactivation treatment processes, as well as the pathogen removal or inactivation credits given to these processes and the criteria the processes must meet to qualify for these credits.

5.9.4 Chemical Inactivation Agents

For inactivation processes using free chlorine residual (chlorination), combined chlorine residual (chloramination), chlorine dioxide and ozone, the designer should refer to the Disinfection Procedure for design options including dosing, contact time and residual concentrations.

5.9.4.1 Free Chlorine

Refer to *Section 6.4.2 – Chlorine Gas* and *Section 6.4.3 – Sodium Hypochlorite* for information on chlorine feed systems.

5.9.4.2 Combined Chlorine

Sources of ammonia for chloramine production are either ammonia gas or water solutions of ammonia (aqua ammonia or ammonium hydroxide) or ammonium sulphate. Refer to *Section 6.4.6 – Ammonia* for information regarding ammonia feed systems.

Addition of ammonia gas or ammonia solution will increase the pH of the water and addition of ammonium sulphate will depress the pH. The actual pH shift may be small in well buffered water but the effects on the disinfecting power and corrosiveness of the water should be considered.

For practical purposes, chloramines generally should not be used for primary disinfection due to the unacceptably high CTs required.

5.9.4.3 Ozone

Ozone must be generated on-site by means of an electrical discharge in oxygen or dry air. Although ozone is a highly effective disinfectant, it does not produce a lasting residual, and is therefore not suitable for secondary disinfection.

As a minimum, bench scale studies should be conducted to determine minimum and maximum ozone dosages for disinfection compliance and oxidation reactions. More involved pilot studies should be conducted when necessary to document benefits and DBP precursor removal effectiveness. Pilot studies should be conducted for all surface waters. Particularly sensitive measurements include gas flow rate, water flow rate and ozone concentration. Consideration should be given to multiple points of ozone addition.

Use of ozone may result in an increase in biologically available organics in the ozonated water and the need for biologically active filtration to stabilize the ozonated water should be evaluated. Ozone use may also lead to increased chlorinated by-product levels if the water is not stabilized and free chlorine is used for distribution protection. When considering ozone, the potential formation of bromate should also be evaluated.

A higher degree of operational skill is required, except in the case of very small packaged generators that provide only a few grams of ozone per day. The ability to develop operator skills should be evaluated in selection of the treatment process. The necessary operator training should be provided prior to plant start-up.

The production of ozone is an energy intensive process; substantial economies in electrical usage, reduction in equipment size and waste heat removal requirements can be obtained by using oxygen enriched air or 100% oxygen as feed and by operating at increased electrical frequency. Refer to *Section 6.4.9 – Ozone* for information regarding ozone generation and feed systems.

5.9.4.4 Chlorine Dioxide

Chlorine dioxide must be generated on-site through the reaction of sodium chlorite with chlorine gas, hypochlorous acid or hydrochloric acid, or through the use of an electrochemical process. Chlorine dioxide is a powerful disinfectant that does not form chlorinated DBPs, however, the formation of chlorite and chlorate by-products should be evaluated. The chlorine dioxide residual from primary disinfection may also be used to maintain a residual through part or all of the water distribution system. Refer to *Section 6.4.4 – Chlorine Dioxide* for information regarding chlorine dioxide generation and feed systems.

5.9.5 Ultraviolet Light Inactivation

5.9.5.1 General

Ultraviolet (UV) radiation may be used for primary disinfection but, since it does not produce a residual, it is not suitable for secondary disinfection. The designer should refer to the Disinfection Procedure for basic UV disinfection design requirements. UV facilities should be designed taking into account reliability and redundancy. At least one extra parallel UV system should be provided to ensure a continuous treated water supply when one unit is out of service. Parallel systems may not be required when there is adequate redundancy of treatment and supply through multiple sources (e.g., more than one well).

UV systems are proprietary. The designer has a choice between different UV technologies such as low pressure, medium pressure (MP) and low pressure high output (LPHO) lamps. Reactors using LPHO lamps are much more energy efficient in producing germicidal light and thus may have lower lifecycle costs. However, LPHO reactors require substantially more space than reactors housing the more intense and much higher temperature MP UV lamps.

The designer should support the choice of lamp/reactor technology by estimating life cycle costs, including the initial cost of purchase, installation costs and on-going lamp replacement costs, and by taking into consideration site specific conditions, such as plant layout, space availability and available head.

The designer should make provisions for water flow delays upon start-up of the UV reactors to allow the lamps to come up to the manufacturer recommended design operating temperature. In smaller installations, it may be economical to select reactors designed for air cooling and "always-on" illumination. Always-on reactors have an added benefit of lengthened lamp life, as frequent on-off cycles substantially reduce lamp life. Where there are extended no-flow periods and fixtures are located a short distance downstream of the UV unit, consideration should be given to UV unit shutdown between operating cycles to prevent heat build-up in the water due to the UV lamp. For medium pressure based reactors, cooling may be required during lamp start-up.

In selecting a UV system, the designer should consider the following major factors (additional information is also available in the USEPA *Ultraviolet Disinfection Guidance Manual* for the *Final Long Term 2 Enhanced Surface Water Treatment Rule*).

5.9.5.2 UV Dosages

The UV dosage required for water disinfection is set by the Disinfection Procedure as a pass-through UV energy of 40 mJ/cm^2 for groundwater that is not under the influence of surface water (where standard SI convention is used this is referred to as a fluence or energy flux of 4 J/m^2).

Laboratory testing of cryptosporidium and giardia confirms 20 mJ/cm^2 is sufficient to provide adequate disinfection of these protist microbes[5]. The designer may provide UV disinfection at that dose where other treatment barriers ensure pathogens such as viruses and bacteria will be adequately disinfected in other treatment barriers.

Each flow path through a reactor receives a different UV dose and as a result it is not possible to estimate dose by using dwell time and UV intensity in an analogous way to chemical disinfection. To confirm the calculated design performance UV reactors need to be bioassay tested by an accredited third party testing organization, to a protocol accepted by the ministry and the manufacturer should provide assurances that reactor supplied conform to the design of the bioassayed sample reactor. The designer should ensure that bioassay calibration data are passed on to the municipality/owner and system operator for operational adjustments.

The designer should ensure that the reactors specified cannot be operated outside the bioassay established range of flows, UV transmittances and the corresponding photometer measured UV intensity. Care should also be taken to ensure that flow disturbances upstream of UV reactors are minimized and conform within the specified limits of the equipment manufacturer.

5.9.5.3 Water Quality

The absorption of light by water contaminants has a major influence on equipment selection and the cost of UV treatment. The designer should assess the available UV transmittance (UVT) data and select a well supported minimum transmission design value for the equipment supplier. UVT is defined as the percentage of 254 nm wavelength UV light that passes through 1 cm (0.4 in) of the water. Many common water contaminants can dramatically reduce the transmittance at UV wavelengths, resulting in higher costs of UV treatment. Since UVT is an important design consideration, the designer should endeavour to obtain data that supports a realistic estimate of the site specific lowest likely UVT.

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[5] In Ontario, certification of conformance to NSF/ANSI standards may be provided by one of the agencies approved for this purpose by the Standards Council of Canada.

Representative influent water quality should be evaluated and pre-treatment equipment, if necessary, should be designed to handle water quality changes. Particulates in water may shield microorganisms, affecting the UV inactivation performance. The scale formation/fouling potential in the UV reactor specific to the quality of the raw water supply should also be considered. Calcium, alkalinity, hardness, iron, pH, UV absorbing organics that adhere to quartz optical surfaces and water temperature are parameters that typically impact sleeve and sensor fouling. The manufacturer should be consulted regarding influent raw water quality requirements.

Chemicals added upstream of the UV system and the natural organic matter content in the influent water affect UVT. Therefore, it is recommended that UV systems be installed downstream of filtration for surface water sources. The designer should refer to the Disinfection Procedure for UV dose and pre-treatment requirements for groundwater and groundwater under the direct influence of surface water.

It is important to select an appropriate UV pass-through dose, based on the Disinfection Procedure. It is also important to ensure that the UV system selected for the design has obtained accredited testing agency bioassay validation to demonstrate that the UV pass-through dose can be achieved under the design conditions, and that the monitoring and control components are in agreement with the reactor bioassay dose over the range of water quality and operating conditions anticipated.

To determine the appropriate cleaning methods, a pilot test should be conducted if the fouling potential of the water is unknown (fouling potential may be difficult to predict based solely on water quality data). Alternatively, both chemical and mechanical cleaning systems may be included in the design.

5.9.5.4 Hydraulics

Headloss through the UV units should be considered where there may be periods of limited hydraulic head available. Typical headlosses range from 150 to 900 mm (0.5 to 3 ft). If the headloss through the UV system (reactor and associated piping, valves, flow control devices) is greater than the available head, modifications to the design or installation of booster pumps may be needed.

5.9.5.5 Operational Control Strategies

Several different control strategies are used to operate UV systems. The designer should consider the control strategies unique to various manufacturers and equipment, and select equipment consistent with the operating philosophy, disinfection strategy and energy efficiency objectives for the treatment plant.

The UV pass-through dose should at all times exceed the minimum dose required for disinfection. To ensure that the actual dose always exceeds this target, the design should be such that the reactor is operated within the bioassay validated range at all times and that the dose delivery and operation conditions are monitored at all times using appropriate strategies that, depending on the technology and bioassay validation protocol under which it was validated, might involve flow rate monitoring, UV lamp intensity monitoring, UV transmittance monitoring and UV dose delivery algorithms that integrate these parameters into a delivered dose.

5.9.5.6 Performance Validation

UV treatment devices should have proof of performance, demonstrating that they can deliver a sufficient UV dose with both an aging and fouling factor applied. The validation testing should include the following operating, design and equipment factors:

- Flow;
- UV intensity as measured by the UV sensor;
- UV lamp status;
- UVT of the water;
- Lamp ageing;
- Lamp sleeve fouling;
- Measurement uncertainty of on-line sensors;
- Failure of lamps or other critical system components; and
- Reactor inlet and outlet configurations.

It is important for UV units to have undergone performance validation by an accredited testing agency and for the manufacturer to certify that the selected reactor is identical to the bioassay tested unit. The validation testing should be to an internationally recognized protocol such as:

- German DVGW *Technical Standard W 294*;
- Austrian ON/ *ÖNORM M 5873*;
- National Water Research Institute-American Water Works Association Research Foundation (NWRI-AwwaRF) *Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse*;
- USEPA *Ultraviolet Disinfection Guidance Manual*; and,
- NSF/ANSI *Standard 55: Ultraviolet Microbiological Water Treatment Systems*.

Class A of NSF/ANSI Standard 55 covers UV treatment systems for point-of-entry applications with flow rates of 1.9 L/s (30 USgpm) or less, therefore, their use in municipal drinking-water systems is limited. However, several of these small units can be used in a bank installation to meet the demands of very small systems if hydraulic and dosing issues are properly addressed, or when using a point of entry treatment design option in accordance with *Drinking-Water Systems* regulation (O. Reg. 170/03) under the *Safe Drinking Water Act, 2002*.

5.9.5.7 Alarms

Many UV reactor signals and alarms are specific to the UV facility and the level of automation used. The following alarms[6] should be considered at each installation:

- **Lamp Age** – Lamp cumulative run-time and number of starts to guide scheduled replacement;
- **Calibration Check of UV sensor** – UV sensor requires calibration check based on operating time;
- **Low UV Validated Dose** – Indicated validated UV dose (based on UV reactor parameters, i.e., flow rate, UV intensity, and UVT) falls below required UV dose;
- **Low UV Intensity** – Intensity falls below validated conditions;
- **Low UV Transmittance** – UVT falls below validated conditions;

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[6] USEPA *Ultraviolet Disinfection Guidance Manual* for the *Final Long Term 2 Enhanced Surface Water Treatment Rule*

- **High Flow Rate** (if applicable; may rely on flow meters) – Flow rate falls outside of validated range;
- **Mechanical Wiper Function Failure** (if applicable) – Wipe function fails;
- **Lamp/Ballast Failure** – Lamp or ballast failure identified;
- **Low Liquid Level** – Liquid level within the UV reactor drops and potential for overheating increases; and
- **High Temperature** – Temperature within the UV reactor or ballast exceeds a setpoint.

The alarms provided for the unit(s) may vary depending on the specific validated conditions, type of UV reactor, manufacturer, dose-monitoring strategy and disinfection requirements.

5.9.5.8 Other Considerations

Water systems using UV should have ready access to a bench-top UVT meter which measures transmission at a wavelength of 254 nm in a path length of 1 cm of water sample to an accuracy of ± 2%. On-line water UVT sensing may be useful where lamp output modulation is practiced, but is not needed where on-line photometry is used to measure light penetrating through the water in the reactor.

The UV assemblies should be accessible for visual observation, cleaning and replacement of the lamps, lamp jackets and sensor window/lens.

The power supply for UV systems should be free from voltage variations exceeding the power supply design range and also free from frequent interruptions. Where disinfection performance must be maintained continuously, an uninterruptible power supply (UPS) is recommended.

The supply pump should be shut down, or alternatively, an automatic shutdown valve should be installed in the water supply line upstream of the UV treatment system that will be activated, whenever the water treatment system loses power or is tripped by the monitoring device when the dosage is below its alarm point. When power is not being supplied to the UV unit, the valve should be in a closed (fail safe) position. Pass-through light intensity monitoring without on-line flow confirmation may be acceptable where flow is restricted to not exceed a bioassay validated design maximum.

The UV housing should be 304L or 316L (low carbon) grade stainless steel.

5.10 AERATION & AIR STRIPPING

5.10.1 General

Aeration and ***air-stripping*** are gas-liquid contact processes. The designer should consider contaminant transfer efficiency, off-gas disposal issues, available hydraulic head, ease of operation, and capital and operating/maintenance costs in evaluating a gas-liquid contact process.

Air stripping is most commonly used in Ontario for the control of methane and/or hydrogen sulphide in groundwater. Due to the relatively low solubility of methane in water, even a splash plate type aerator may provide sufficiently effective treatment. Appropriate ventilation should be provided to ensure that methane concentrations do not reach the Lower Explosive Limit (LEL).

Air stripping for hydrogen sulphide removal has specific limitations, as carbon dioxide is also stripped, leading to pH increases and the potential for scaling. Pilot testing should be conducted to ensure sulphide levels can be sufficiently reduced without causing scaling issues. If air stripping can not be used, alternative chemical processes to reduce sulphide concentrations to inoffensive levels should be considered.

The feasibility of aerators or air strippers should be evaluated through pilot studies. The pilot test should evaluate a variety of loading rates and air-to-water ratios at the peak contaminant concentration. Consideration needs to be given to removal efficiencies, oxidation rates or scaling due to incidental carbon dioxide stripping, when multiple contaminants are present.

The materials of construction, including all material in contact with the water, should be corrosion resistant (*Section 3.26 – Chemicals and other Water Contacting Materials*).

Aeration and air-stripping processes include multiple tray, spray aerators or towers, pressure aerators and packed towers, spraying, diffused air, cascades and mechanical aeration. Since these processes are not common in Ontario, specific design guidelines are not included in this document. The designer should consult other guidelines such as *Recommended Standards for Water Works*[7] (Ten-State Standards) and with the equipment manufacturer for all gas-liquid contact processes.

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[7] *Recommended Standards for Water Works* (Ten-State Standards), *Policies for the Review and Approval of Plans and Specifications for Public Water Supplies, A Report of the Water Supply Committee of the Great Lakes–Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers*. The document is published by Health Research Inc., Health Education Division, P.O. Box 7126, Albany NY 12224 (518)439-7286 www.hes.org.

5.11 SOFTENING

5.11.1 General

The softening process selected should be based upon the mineral qualities of the raw water and the desired finished water quality in conjunction with requirements for disposal of sludge or brine waste, capital and operating/maintenance costs. Methods of hardness reduction other than lime softening should be investigated when the sodium and dissolved solids concentrations are of concern.

5.11.2 Lime or Lime-Soda Process

Design guidelines for rapid mix, flocculation and sedimentation are described in *Section 5.4 – Coagulation and Flocculation* and *Section 5.5 – Clarification*. Additional consideration should be given to the following process elements:

- **Hydraulics** – When split treatment is used, the bypass line should be sized to carry total plant flow and an accurate means of measuring and splitting the flow should be provided;
- **Aeration** – Determinations should be made of the carbon dioxide content of the raw water. When concentrations exceed 10 mg/L, the economics of removal by aeration as opposed to removal with lime should be considered if it has been determined that dissolved oxygen in the finished water will not cause corrosion problems in the distribution system;
- **Chemical feed point** – Lime and recycled sludge should be fed directly into the rapid mix basin;
- **Rapid mix** – Rapid mix basins should provide not more than 30 seconds detention time with adequate velocity gradients to keep the lime particles dispersed;
- **Stabilization** – Equipment for stabilization of water softened by a lime or lime-soda process should be provided;
- **Sludge collection** – Mechanical sludge removal equipment should be provided in the sedimentation basin. Sludge recycling to the rapid mix should be provided;
- **Sludge disposal** – Provisions should be included for proper disposal of softening sludges (*Section 11.2.6 – Precipitative Softening*); and
- **Plant start-up** – The plant processes should be manually started following shutdown.

5.11.3 Ion Exchange Process

The iron and/or manganese concentration should not exceed 1.0 mg/L and the turbidity should be less than 5 NTU in the water applied to the ion exchange resin. The ion exchange units may be of pressure or gravity type, of either an upflow or downflow design. Automatic regeneration based on volume of water softened should be used. A manual override should be provided on all automatic controls.

Other design considerations include:

- **Exchange capacity** – The design capacity for hardness removal should not exceed 46 kg/m^3 (22,000 gr/ft^3) when resin is regenerated with 0.14 kg (0.3 lbs) of salt per kg of hardness;
- **Depth of resin** – The depth of the exchange resin should not be less than 900 mm (3 ft);
- **Flows** – The flow rate should not exceed 17 m/h (7 $USgpm/ft^2$) and the backwash rate should be 14 to 20 m/h (6 to 8 $USgpm/ft^2$). Rate-of-flow controllers or the equivalent should be installed;
- **Freeboard** – The freeboard will depend upon the size and relative density of the resin and the direction of water flow. Generally, the washwater collector should be 600 mm (24 in) above the top of the resin on downflow units;
- **Underdrains and supporting gravel** – The bottoms, strainer systems and support for the exchange resin should conform to criteria provided for rapid rate gravity filters (*Section 5.6.2 – Rapid Rate Gravity Filters*);
- **Brine distribution** – The design should ensure even distribution of the brine over the entire surface of both upflow and downflow units;
- **Cross-connection control** – Backwash, rinse and air relief discharge pipes should be installed in such a manner as to prevent any possibility of backsiphonage;
- **Bypass piping and equipment** – A bypass should be provided around softening units to produce a blended water of desirable hardness. Totalizing meters should be installed on the bypass line and on each softener unit. The bypass line should have a shutoff valve and should have an automatic proportioning or regulating device. In some installations, it may be necessary to treat the bypassed water to obtain acceptable levels of iron and/or manganese in the finished water;

- **Resins** – Silica gel resins should not be used for waters having a pH above 8.4 or containing less than 6 mg/L silica and should not be used when iron is present. When the applied water contains a chlorine residual, the resin should be of a type that is not damaged by residual chlorine. Phenolic resin should not be used;

- **Sampling taps** – Smooth nosed sampling taps should be provided for the collection of representative samples. The taps should be located at the softener influent, effluent and blended water. The sampling taps for the blended water should be at least 6 m (20 ft), or at a distance where sufficient mixing has occurred, downstream of the point of blending. Sampling taps should also be provided on the brine tank discharge piping;

- **Brine and salt storage tanks** – Salt dissolving or brine tanks and wet salt storage tanks should be covered and be corrosion-resistant. The make-up water inlet should be protected from backsiphonage. Water for filling the tank should be distributed over the entire surface by pipes above the maximum brine level in the tank. The tanks should be provided with an automatic declining level control system on the make-up water line. Wet salt storage basins should be equipped with hatchways for access and for direct dumping of salt from truck or railcar. Openings should be provided with raised curbs and watertight covers having overlapping edges similar to those required for finished water reservoirs. Overflows, where provided, should be protected with corrosion resistant screens and should terminate with either a turned-down bend having a proper free fall discharge or a self-closing flap valve. Two wet salt storage tanks or compartments designed to operate independently should be provided. The salt should be supported on graduated layers of gravel placed over a brine collection system. Alternative designs which are conducive to frequent cleaning of the wet salt storage tank may be considered;

- **Salt and brine storage capacity** – Total salt storage should have sufficient capacity to store in excess of 1½ full loads of salt, and provide for at least 30 days operation;

- **Brine pump or eductor** – An eductor may be used to transfer brine from the brine tank to the softeners. If a pump is used, a brine measuring tank or means of metering should be provided to obtain proper dilution;

- **Waste disposal** – Suitable disposal should be provided for brine waste (*Section 11.2.5 – Ion Exchange Processes*). The designer could consider using part of the spent brine for a subsequent regeneration;

- **Construction materials** – Pipes and contact materials should be resistant to the aggressiveness of salt; and

- **Housing** – Bagged salt and dry bulk salt storage should be enclosed and separated from other operating areas in order to prevent damage to equipment.

5.12 IRON & MANGANESE CONTROL

5.12.1 General

Iron and manganese are frequently encountered nuisance parameters that seriously affect aesthetic water quality. They can cause visible water colour and turbidity and cause brown and black staining of plumbing fixtures and washed clothing. These effects can occur at specific locations in a distribution system even when the concentration of either metal in the treated water entering the distribution system is below the Ontario aesthetic objective stated in the Technical Support Document. This occurs as a result of precipitation and redissolution processes resulting in pockets of local high concentrations.

Elevated iron and manganese concentrations occur most frequently with groundwater sources. Surface water sources may also be contaminated with the metals at anoxic depths in lakes or seasonally under long-duration ice cover. Five control technologies[8] are in common use in Ontario, including:

- Removal of iron by air or chlorine oxidation followed by sedimentation;
- Masking the impact of iron by "sequestering";
- Removal by ion exchange water softeners;
- Removal by "greensand" processes; and
- Pre-oxidation and regular chemically assisted depth or membrane filtration.

Very high levels of iron and manganese of 5 mg/L or more can be treated by lime softening processes. This is costly and rarely necessary in Ontario where alternative, nearby sources may be found with lower iron or manganese concentrations. Refer to *Section 5.11 – Softening* for lime softening guidelines.

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[8] A sixth control method of biofiltration under closely controlled and optimized dissolved oxygen content has been applied in North America. By controlling both oxygen content and pH, a specific bacterial culture develops and the process is optimized for either iron or manganese removal. The bacteria precipitate the metals and periodic gentle backwashing removes accumulated metals without completely stripping the bacteria. Successful operation requires sophisticated and skilled operator attention to maintain the specific bacterial population required.

5.12.2 Air/Chlorine Oxidation of Iron

In groundwater treatment systems where iron levels are near the aesthetic objective, a simple sedimentation process may result in acceptable finished water quality. On exposure to active chlorine or oxygen, divalent or ferrous iron is rapidly oxidized to the effectively insoluble trivalent or ferric state. In favourable circumstances the ferric iron may precipitate as a readily separating brown solid without additional complex treatment. Oxygen and chlorine oxidize manganese at too slow a rate for effective removal unless the manganese is present at very low levels relative to the iron concentration. However in some cases the newly formed iron precipitate surface is found to at least be partially effective in adsorbing the manganese.

5.12.3 Sequestering with Silicates or Polyphosphates

Sequestering is an inexpensive and commonly adopted palliative measure for iron control that slows, but does not stop, the perceptible formation of the typical yellow/brown colour. Sequestering temporarily traps and then slowly releases oxidized iron into the water from a complexed/colloidal form. At most, the effect lasts for only a few days. The eventual failure of sequestration is due to calcium ions progressively displacing the iron so that the regular perceptible yellow-brown colour becomes visible. (This happens rapidly in hot water forming sediment in domestic hot water heaters.)

Effective sequestering depends on the sequestering agent, either freshly hydrated silica or polyphosphate ions, intercepting ferric iron ions as they are formed by chlorine oxidation. The forming precipitate of oxidized iron is then physically trapped and kept in a colourless colloidal suspension by the sequestrant. This process of sequestering the iron must be completed during the few seconds before hardness cations such as calcium take up and block any further sequestrant activity. The designer of a sequestering system should first confirm suitability of the source water for sequestering by:

- On-site colorimetric testing of fresh water samples to confirm that the iron content is mostly in the chemically reduced divalent form; and
- Confirming through on-site or regular total metals analytical scans that manganese levels are low relative to the iron content of the water.

Designers are reminded that GUDI sources may show substantial seasonal variations in both iron and manganese speciation and concentrations.

The approximate sequestrant dosage and the likely delay time to perceptible colour development should be confirmed by on-site testing[9]. If a significant delay in colour formation (relative to the water retention time in the distribution system) is confirmed by on-site testing, the following equipment should be provided for full scale silicate sequestering:

- A locally placed day tank with lid for hypochlorite;
- A locally placed day tank with lid for silicate, sized for up to two weeks of water treatment that allows for 1:2 dilution of silicate (for viscosity reduction), preferably with softened water. Greater dilution ratios or longer storage of diluted silicate should be avoided, as these conditions reduce sequestering effectiveness, particularly in warm seasons;
- Feed pumps, preferably of the peristaltic type, or other pumping arrangements, adapted to provide continuous, effectively pulse free addition of the hypochlorite and silicate to the flowing water stream;
- Injectors of the "duck bill" or other scale blockage resistant variety that allow for injection of the silicate and hypochlorite to the centre of a rapidly flowing stream to aid in the necessary rapid dispersion of the two chemicals. Best results are commonly achieved with hypochlorite added a metre or more upstream of the silicate injector location and where mixing is assisted by use of nearby downstream elbows or other means. Several tappings should be made to allow for easy injector relocation and spacing changes; and
- A nearby downstream wide bore sample tap that allows for easy collection of 20 L (5.28 USgal) samples for observation and dosage optimization.

Polyphosphate blends are considerably more costly but may be as effective as silicate for sequestering. However they have been documented in some cases to cause lead leaching in domestic plumbing. Polyphosphate is usually most effective when injected close to the hypochlorite injector location. Designers should note that divalent manganese, in the absence of an excess of iron, is not sufficiently rapidly oxidized by hypochlorite for effective sequestering. Often where this is attempted, the manganese precipitates during passage through the distribution system causing the usual black staining. Other oxidants may work more rapidly but because of the additional complications involved, their use is not generally merited. Where manganese concentration approaches the aesthetic objective levels, removal often may be a more appropriate treatment option.

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[9] This testing may be effectively carried out in vigorously agitated 20 L (5.28 USgal) samples in white pails. Simultaneously add enough diluted hypochlorite to provide a free chlorine residual while also adding varying doses of freshly prepared diluted silicate or polyphosphate to cover the dosage range of 1 to 6 mg/L to a series of pails of freshly collected well water. A control sample with hypochlorite alone should be prepared at the same time. The pails should be covered and stored in a cool dry place and periodically observed under bright illumination for colour development over the following few days.

Groundwater sources tend to show increasing iron levels as they age. Designers should consider providing space to accommodate future installation of removal equipment where there is evidence from other local wells that this may eventually become a necessary treatment upgrade.

Refer to *Chapter 6 - Chemical Application* for guidelines regarding chemical storage, handling and feed systems,

5.12.4 Ion Exchange in Regular Softeners

In small groundwater systems it is frequently attractive to consumers to have the water hardness reduced by having all or a substantial fraction of the water passed through an ion exchange softener. An added feature of ion exchange softening is that dissolved iron and manganese are also removed in the same way as calcium and magnesium on the exchanger resin beads. Regeneration of the resin with salt brine displaces calcium and the divalent iron and manganese into the spent brine which then should be safely disposed (*Section 11.2.5 – Ion Exchange Processes*).

This process is quite effective but operates only on divalent and non-organically bound iron and manganese and only reduces concentration in proportion to the ratio of softened to non-softened/by-passed water. Designers should be aware that as wells age it is frequently observed that increasing contamination occurs with iron and manganese in oxidized form and with sloughed biofilm and other debris from bacterial activity. These materials may plug protecting cartridge filters and the resin causing frequent, premature and costly replacement. In addition, exposure of resin containing adsorbed divalent iron and manganese to oxygen or other oxidants causes effectively permanent loss of resin capacity.

For these reasons, the application of this technology should be restricted to raw water where on-site colorimetric testing shows relatively low levels of iron and manganese with a high proportion present in the divalent form. Refer to *Section 5.11.3 – Ion Exchange Process* for ion exchange guidelines.

5.12.5 Greensand Type Processes

Historically this process depended on using greensand, a manganese ore, as the filter media downstream of the addition of a chemical oxidizing agent. Media made from manganese ore particles has long been replaced commercially by more robust proprietary media, but the name for the overall process retained. The proprietary media used are surface treated to physically adsorb and retain an oxidized iron and/or manganese surface layer. Filter media should conform to NSF/ANSI *Standard 61: Drinking Water System Components - Health Effects* and the applicable AWWA *Standard B101: Precoat Filter Media* or AWWA *Standard B102: Manganese Greensand for Filters*.

The process is selective for the iron and manganese and does not involve removal of other contaminants, such as hardness components. As a result the equipment is usually more compact than for ion exchange softening or for conventional chemically assisted filtration.

Deposited material on the media is periodically partially removed by backwashing. Backwashing should be limited in intensity to avoid completely stripping the essential base catalytic surface from the media.

Both designers and operators of greensand systems should be aware that failure to maintain the activity of the catalytic layer can lead to sudden failure of the process and this will require replacement of the media. In some cases, the maintenance of media activity requires a continuous feed of potassium permanganate solution (often with hypochlorite), while in others a regular soaking of the media in the permanganate solution and operation of the filter with a hypochlorite feed alone is sufficient. If iron alone is to be removed, the media may not require catalytic activity at all, just a capability to adsorb and retain the precipitated iron; therefore permanganate use may not be necessary.

The presence of iron and manganese is often attributed to biological activity in the aquifer near wells bores. A secondary and frequent consequence is the presence of sloughed-off biofilm and particulate bacterial waste in the raw water. The presence of these particulates influences the optimum media bed shape and media selection, with conical beds and dual media more often adopted where there is heavier contamination.

Selecting filter loading rates, media type and depths, run duration to backwash and oxidant regenerant/oxidant and dose control are complex issues dependent on a detailed understanding of how the technology responds to the specific raw water characteristics. On occasion, the manganese may be found to be at least partly resistant to oxidation because of association with organics. In such cases, the use of chlorine dioxide or ozone may be required as they are faster acting oxidants. Specialist media supply companies are commercially active in this field in Ontario and can provide information regarding site/water adapted equipment, media and full scale operating instructions together with performance guarantees. Short term bench and on-site pilot testing lasting no more than a few days is recommended.

Greensand type processes will remove pathogens in most circumstances; however, because coagulant activity only occurs on the catalytic media particle surface, the efficiency may be very low. As a result no disinfection log credits are allowed for pathogen removal under the Disinfection Procedure.

5.12.6 Preoxidation & Chemically Assisted/Membrane Filtration

Where pathogen removal is required, this category of treatment may be preferred as it combines the required pathogen removal and associated log credits for filtration with the control of iron and manganese. The designer may consider the following options following use of a selected oxidant:

- Conventional chemically assisted filtration with granular filtration media of the type required for turbidity control, coupled with appropriate coagulation/flocculation processes for pathogen removal log credits; and
- Membrane filtration with, or in some cases without, coagulant chemical or aid. Time is required for the agglomeration of iron and manganese particles for effective filtration and/or for the action of coagulant. Coagulant use is not required for log removal credits for some pathogens.

In some small systems with iron contamination, a combination of hypochlorite oxidation on granular media, with or without downstream cartridge filtration, may be an effective low cost alternative.

The use of permanganate as an oxidant or a combination of permanganate with hypochlorite is commonly effective with GUDI sources. The oxidant should be added upstream of the coagulant and sufficient time allowed for effective completion of the metal oxidation before coagulation. Oxidation may be slowed in winter conditions as GUDI source temperatures can be close to freezing and also the presence of natural organics may also slow the reactions by forming chemical complexes with manganese. The designer should take account of these factors particularly with pressure filter systems where the scale of the system can have a very significant influence on the cost of pressure vessels required to provide adequate residence time. On occasion, oxidation reactions can be so slow that it may be cost effective to consider the use of more rapidly acting oxidants such as ozone, or providing two stage treatment comprising regular greensand contact upstream of a form of regular filtration.

The designer should make provision to avoid a potential consequence of use of permanganate (or ozone with manganese containing raw water as this combination can produce permanganate). Permanganate is strongly coloured and if present in sufficient amount can have the undesired consequence of a faint permanganate pink colour becoming visible in finished water. While this is not an immediate health issue, it will cause consumer alarm. The use of available on-line colorimetry for permanganate or ozone dose adjustment should be considered.

Some surface water supplies can also require seasonal iron and manganese treatment. Typically, surface sources that require treatment for iron and manganese control have long duration ice cover and/or deep lake intakes and usually require variable and carefully adjusted treatment modification seasonally before spring break up. Provision of means for addition and mixing of permanganate solution some minutes upstream of coagulant addition is desirable for effective removal of the metals in the sedimentation and filtration steps.

5.13 NATURAL ORGANIC MATTER CONTROL

5.13.1 General

Natural organic matter (NOM) has traditionally been partly removed from drinking water for aesthetic reasons as it often imparts colour to the water. The low molecular weight fractions of NOM are mostly responsible for chlorination by-product formation and therefore a reduction of the NOM level is desirable. NOM may also affect water treatment processes including coagulation (dosage and optimum pH), membrane filtration (fouling), disinfection (chemical demand or UVT), activated carbon usage rates and distribution system water quality (biological regrowth potential). Enhanced coagulation can reduce the fraction of the chlorine by-product forming NOM in filtered water, but it is often found that other techniques are easier to use in controlling by-product formation.

5.13.2 Activated Carbon

GAC can be used for reducing the NOM concentration, and may also be operated in a biologically active mode for NOM reduction. However, the use of GAC to adsorb NOM is not generally very effective or economically attractive as the GAC rapidly loses adsorption capacity. This occurs even when GAC is operated as an active biofilter support. However, GAC use may be necessary as the only moderately economic recourse in controlling some taste and odour events, such as those caused by geosmin and methylisoborneol (MIB).

The empty bed contact time (EBCT) required for substantial NOM removal typically varies from 10 to 20 minutes. Several months of pilot testing is needed to determine the EBCT and other variables described in *Section 5.8 – Soluble Contaminant Removal Processes*.

5.13.3 Nanofiltration

A large fraction of the NOM can be removed with membranes having a molecular weight cutoff of 1000 or less. This process can be costly as relatively high pressures are used and pre-treatment is needed to protect the membranes from particulate accumulation, as the maximum backwash flow rates available with such "tight" membranes are too low to dislodge accumulated solids. Nanofiltration has not yet found wide application in Ontario, although there are some installations across Canada. Experience with nanofiltration to date has not been sufficient to provide specific design guidelines; the designer should therefore consult the manufacturer if considering nanofiltration.

5.14 TASTE & ODOUR CONTROL

5.14.1 General

Offensive tastes and odours should be controlled at all surface water treatment plants. Plants treating water that is known to have taste and odour problems should be designed with several control processes so that the operator will have flexibility in operation. Pilot-scale and/or in-plant studies are recommended to determine the best treatment process(es).

5.14.2 Microscreening

Microscreens or microstrainers are mechanical screens with very small openings capable of removing suspended matter from the water by straining. Microscreens generally follow immediately after coarse screens. Microscreens are used during periods when the raw water contains nuisance organisms such as algae when heavy loadings may negatively impact downstream processes (e.g., granular and membrane filtration).

Designers should consider the:

- Expected loading and duration of the algae blooms;
- Corrosiveness of the water;
- Effect of chlorination when required as pre-treatment;
- Duplication of units for continuous operation during equipment maintenance;
- Automated backflushing; and
- Alternative technologies such as dissolved air floatation (*Section 5.5.5 – Dissolved Air Flotation*).

The design should provide:

- By-pass arrangements;
- Protection against backsiphonage when treated water is used for washing; and
- Proper disposal of wash water.

5.14.3 Oxidation

Many common taste and odour causing substance can be chemically oxidized to less odorous substances or mineralized to carbon dioxide and water. Chemical oxidants include chlorine, monochloramine, chlorine dioxide, potassium permanganate, hydrogen peroxide and ozone. Advanced oxidation processes (*Section 5.14.4 – Advanced Oxidation*) and aeration (*Section 5.10 – Aeration and Air Stripping*) may also be effective.

Taste and odour control chemicals (e.g., chlorine and potassium permanganate) should be added sufficiently upstream of other treatment processes to ensure adequate contact time for an effective and economical use of the chemicals. Considerations should also include the potential for by-product formation.

Refer to *Chapter 6 - Chemical Application* for guidelines relating to chemical handling, storage and feeding,

5.14.4 Advanced Oxidation

Advanced oxidation processes (AOPs) are processes that provide powerful oxidizing conditions to mineralize organic water contaminants. AOPs involve the use of any one of several possible combinations of UV, hydrogen peroxide, ozone and titanium dioxide.

AOPs depend on extremely unstable radical chemical species that react very rapidly with any organic material present. Any NOM which may also be present in the water is mineralized at a similar rate to the target contaminants. As a result, AOPs should only be used on very low to trace amounts of specific contaminants such as N-nitrosodimethylamine (NDMA) or 1-4 dioxane, and only in water with low NOM content. Bench and/or pilot scale evaluation using the specific source water and covering seasonal variations is needed to establish effectiveness and costs.

AOPs that use hydrogen peroxide may produce water with a peroxide residual that behaves like chlorine in colourimetric tests, reacts with and destroys free chlorine, and can upset downstream biological processes. Thiosulphates, sulphites or GAC can be used to destroy peroxide residuals.

5.14.5 Activated Carbon

A wide range of water contaminants that cause offensive tastes and odours can be at least partly removed by contact with activated carbon. Activated carbon may be in powdered (PAC) or granular (GAC) form. PAC is used as a continuously fed additive that must be removed following the required contact time, but before primary disinfection, by processes such as chemically-assisted filtration. GAC is used in fixed contactor beds. The selection decision between using PAC or GAC should be based on the nature and concentration of the contaminant to be removed and a wide range of site and process specific considerations.

5.14.5.1 Powdered Activated Carbon

PAC should be added as early as possible in the treatment process to provide maximum contact time. The designer should consider the removal of the PAC and its impact on the filtration process, as well as disposal of the sludge produced by the PAC addition. Activated carbon should not be added near the point of chlorine or other oxidant application, as the adsorption capacity of the carbon decreases due to chemical reactions that convert chlorine to chloride and other oxidants to inactive materials.

The rate of feed of carbon in a water treatment plant depends upon the taste and/or odour reduction needed and the contact time available, but provision should be made for adding up to at least 40 mg/L. Pilot scale testing is recommended to determine contact time and the range of dosages required.

PAC can be added as a pre-mixed slurry or by means of dry-feed equipment as long as the carbon is thoroughly wetted before its introduction to the water to be treated. Refer to *Section 6.4.13 – Powdered Activated Carbon* for more information on storage and feeding of PAC.

5.14.5.2 Granular Activated Carbon

Granular activated carbon (GAC) can be used in place of anthracite in granular filters (*Section 5.6 – Granular Media Depth Filtration*) or in separate contactors (*Section 5.8 – Soluble Contaminant Removal Processes*). When GAC is used as a layer in filters, the GAC cannot be removed from service or by-passed during periods when tastes and odours are not a problem. This potentially shortens the life of the GAC for taste and odour control as other compounds are adsorbed onto the active sites on the carbon. GAC contactors however can be by-passed in winter months to extend the effective bed life.

The empty bed contact time (EBCT) required for taste and odour control depends on the nature of the taste and odour compounds and typically varies from 10 to 30 minutes. Pilot testing is recommended to determine EBCT and expected bed operation life. Where the contaminant to be controlled is present only in short term seasonal excursions, pilot work may be useful to indicate effective bed life and the potential need for off-line contactors.

GAC in filters or separate contactors may be operated in a biologically active mode for taste and odour control (*Section 5.8 – Soluble Contaminant Removal Processes*).

5.15 NITRITE/ NITRATE REMOVAL

The following treatment processes are generally considered acceptable for nitrate/nitrite concentration reduction: anion exchange, reverse osmosis, nanofiltration and electrodialysis. Although these treatment processes, when properly designed and operated, will reduce the nitrate/nitrite concentration in the treated water to acceptable levels, primary consideration should be given to obtaining water from an alternate water source or reducing the nitrate/nitrite levels through blending and/or better control of nitrogen fertilizer application, septic systems and waste disposal.

Refer to *Section 5.11.3 – Ion Exchange Process* for ion exchange guidelines. High levels of sulphate, chloride or dissolved solids may interfere with an ion exchange process. In these cases, reverse osmosis, nanofiltration or electrodialysis should be investigated. The equipment manufacturer should be consulted for guidelines for these processes.

5.16 ARSENIC REMOVAL

The form in which arsenic is present in water is critical in the selection of the treatment technology for arsenic removal. The use of pre-oxidation processes may be necessary to oxidize As(III) to As(V) for optimum treatment performance. Pre-treatment may also be needed to adjust pH and to remove competing ions such as fluoride, sulphate and silicate as well as to reduce total dissolved solids. Issues to be evaluated when considering pre-treatment processes include by-product formation and membrane fouling potential if membranes are used.

At this time, the technologies available for removing arsenic from municipal drinking-water systems include coagulation/filtration, iron based adsorbents, lime softening, activated alumina, ion exchange, reverse osmosis, manganese greensand filtration, adsorption/filtration and electrodialysis. Point-of-entry treatment devices may be practical for small systems (treatment requirements in O. Reg. 170/03 are related to microbiological contaminants; other contaminants, such as arsenic, are outside the scope of this regulation). Blending of water sources or treating a portion of the water (sidestream treatment) to reduce the concentration of arsenic in water delivered to the consumer are other potential arsenic control techniques. Additional guidance in process selection is available from the USEPA and the AWWA.

Pilot testing of any treatment process is recommended. Disposal of residuals is an important consideration in the design of arsenic removal processes.

5.17 FLUORIDE REMOVAL

The designer should refer to the Technical Support Document where naturally occurring fluoride is above the standard established in O. Reg. 169/03. Methods to reduce fluoride include ion exchange, reverse osmosis, coagulation/flocculation processes with high alum dosage, and proprietary technologies.

If fluoride is to be added to the water, the total concentration of naturally occurring fluoride plus added fluoride should be in the range specified in the Technical Support Document. Sodium fluoride, sodium silicofluoride and hydrofluosilicic acid are common chemicals used for fluoridation. Refer to *Section 6.4.14 – Fluoride* for guidelines regarding chemical storage, handling and feeding.

5.18 INTERNAL CORROSION CONTROL

5.18.1 General

Metals that are in contact with water containing oxygen or chlorine or metals exposed to acidic conditions alone will undergo corrosion. Electrical contact between different metals and stray electric currents also can cause localized corrosion. Distribution system wide corrosion and the corresponding water quality deterioration can usually be reduced through water treatment plant process adjustment or by addition of selected chemicals.

Parameters such as the ***Langelier Saturation Index***[10] that are based exclusively on water solution chemistry, and which do not take into account processes occurring at the metal surface, are presently considered unreliable indicators of changes that may slow corrosion. Also, industrial corrosion coupon testing is not reliable unless long duration procedures are conducted with standardized hydraulic conditions. Simulated distribution testing (pipe loop testing) is an expensive, time consuming procedure and may provide unreliable results.

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[10] The Langelier index does predict potential for carbonate scaling as this is dependent on solution properties alone and is not significantly influenced by activity at the corroding surfaces. Carbonate scale has been found not to significantly affect corrosion rates in number of studies.

A suggested approach is to adopt a methodical full-scale testing procedure such as:

- Establishing a baseline measure of the existing rate of corrosion by documenting water quality complaint location and frequency, or preferably by adopting widespread sampling following a selected protocol (e.g., the USEPA *Lead and Copper Rule*); or,
- Making limited water quality changes such as pH shift of +0.5 units or soda ash addition of up to 10 mg/L, and confirming the effectiveness of the adopted corrosion control method after allowing 6 to 9 months for the corrosion process to adjust.

The most reliable indication of the effectiveness of the above procedure can be obtained by setting aside a section of the distribution system for water quality adjustment and comparing sampling results from this area with that from the rest of the distribution system. This eliminates the effect of seasonal water quality changes that may otherwise obscure indications of effectiveness level.

Increases in pH, alkalinity and carbonate buffer content are the most consistent methods for reducing the rate of corrosion. Increasing the carbonate buffer level is particularly recommended for systems treating very soft water.

It is recommended that corrosion rate estimations be used to validate the efficacy of these water quality changes in reducing corrosion. Corrosion rates are commonly observed to take from 6 months to a year to stabilize after changes in water quality. A reliable testing technique is to make changes to water composition in one area of a distribution system while leaving the water composition unchanged in the remainder of the system, and comparing testing results from the two areas after a period of 6 months to a year.

Very soft and acidic water has been known to be capable of causing health-significant releases of lead from lead service lines, from domestic plumbing that may have used lead containing solder and from lead containing brass fittings. However lead levels in flushed samples from domestic taps rarely exceed the O. Reg. 169/03 lead standard where the water has alkaline pH, moderate alkalinity and carries an adequate secondary disinfectant residual. An exception to this may occur with major changes in water composition such as with uncontrolled and wide pH variations, new mixing with water from another source, new addition of a corrosion inhibiting chemical or changeovers from free chlorine to chloramine as secondary disinfectant. It is prudent to track lead level changes in well flushed samples taken from consumer taps during planned changes to water composition, and if necessary to slow or reverse the changes, and/or plan removing the lead service lines.

5.18.2 Raising pH, Alkalinity & Carbonate Buffer Level

Sodium carbonate addition provides simultaneous and easily controlled increases in pH, alkalinity and carbonate buffer capacity. Addition may be by feeding solid soda ash or by solution addition.

The use of 50% sodium hydroxide solution increases pH and alkalinity but does not increase the buffer capacity and may be of limited effectiveness with very soft water. In addition, pH control can be difficult with sodium hydroxide. 50% sodium hydroxide solution can freeze at moderately depressed temperatures and handling hazards exist.

Combinations of sodium hydroxide with carbon dioxide offer maximum flexibility in adjusting finished water pH, alkalinity and carbonate buffer capacity but relatively complex controls may be needed.

The use of lime to raise pH and alkalinity in the water has been largely discontinued because of the tendency to plug feed lines and to create excursions in finished water turbidity.

5.18.3 Commercial Corrosion Inhibitors

Where adjustments to water quality parameters such as chlorine residual, pH, alkalinity and carbonate buffer strength prove insufficient to control corrosion rates, the use of special additives as listed below should be considered.

Sodium silicate in dosage rates of up to 10 mg/L has been shown to suppress red water in some systems.

The addition of ortho-phosphoric acid has been used at a 3-5 mg/L in some systems with red water problems. Sodium ortho-phosphate may be used in the same way as the acid without the pH depressing effect. Several different grades are available depending on the sodium/phosphate ratio. Some success has been also reported in red water control with polyphosphates and also with ortho-phosphate/polyphosphate blends. The designer should be aware that in some systems, elevated lead levels have occurred with these inhibitors. The addition of phosphorus containing substances will add to the phosphorus load entering sewage treatment facilities and may encourage biofilm growth in distribution systems.

Zinc salts are also known to suppress microbial activity and have provided some reductions in red water problems. Use of zinc compounds may affect downstream sewage treatment.

5.18.4 Carbon Dioxide Reduction by Aeration

The carbon dioxide content of an aggressive and corrosive groundwater may be reduced by aeration. Refer to Section 5.10 – Aeration and Air Stripping for a summary of aeration processes. The designer may consult a guideline such as *Recommended Standards for Water Works*[11] (Ten-State Standards) and with the equipment manufacturer for detailed aeration guidelines.

5.18.5 Limestone Chip Contactors

Percolating water through a bed of limestone chips at the end of the water treatment process has been used to neutralize acid and suppress iron corrosion in very small water systems. Bench testing is recommended with selected commercial chips and treated water on site to confirm effectiveness.

Limestone chips can not be certified to regular NSF/ANSI standards but may be considered on a site specific basis at the discretion of the Director

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[11] *Recommended Standards for Water Works* (Ten-State Standards), *Policies for the Review and Approval of Plans and Specifications for Public Water Supplies, A Report of the Water Supply Committee of the Great Lakes–Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers*. The document is published by Health Research Inc., Health Education Division, P.O. Box 7126, Albany NY 12224 (518)439-7286 www.hes.org.

CHAPTER 6

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CHAPTER 6

CHEMICAL APPLICATION

This chapter provides general information regarding chemical feed systems, equipment, application points, as well as recommendations for storage and handling. Specific information concerning chemical processes and the use of the chemicals described herein is provided in the appropriate sections of *Chapter 5 – Treatment*.

Section 6.4 – Specific Chemicals provides more detailed information about some of the chemicals which are commonly used in water treatment plants in Ontario. For all chemicals, the designer should consult the chemical manufacturer/supplier regarding chemical functionality and safety and for guidance in designing the chemical feed system. AWWA Standards also provide information on specific chemical safety, handling and storage.

In addition, the use, storage and handling of any hazardous materials should be in accordance with federal and provincial legislation for *Workplace Hazardous Materials Information System* (R.R.O. 1990, Regulation 860) under the *Occupational Health and Safety Act* (OHSA), the *Building Code* (O. Reg. 350/06) under the *Building Code Act, 1992* and the *Fire Code* (O. Reg. 388/97) under the *Fire Protection and Prevention Act, 1997*.

6.1 GENERAL

6.1.1 Plans & Specifications

Plans and specifications should include descriptions of feed equipment including maximum and minimum feed ranges, dosage capabilities at maximum production rates, location of feeders, piping layout and points of application, storage and handling facilities, specifications for chemicals to be used, operating and control processes, and descriptions of monitoring equipment and procedures. Process flow diagrams (PFD) showing all process components including reactors, pumps, chemical feeders, valves, analyzers and the location of all points of chemical addition, effluent sampling and monitoring should be included. A narrative statement of the intended chemical process control philosophy, treatment ranges, and process and instrumentation diagrams (P&ID) showing the operation control arrangements for all processes should also be included.

6.1.2 Chemicals & Water Contacting Materials

Requirements for chemicals and water contacting materials are discussed in *Section 3.26 – Chemicals and Other Water Contacting Materials*.

6.1.3 Chemical Application

Chemicals should be applied to the water at such points and by such means as to ensure safety for consumers and operators, ensure efficacy of treatment and the ability to respond to changes in water quality, ensure sufficiently rapid and effective mixing of the chemicals with the water and provide maximum flexibility of operation through provision of multiple points of application, when appropriate. Sampling points should be designed for effective, timely and representative monitoring of chemical application.

6.1.4 General Equipment Design

The equipment design should ensure that feeders will be able to accurately supply, at all times, the necessary amounts of chemicals throughout the design range of dosage and water flows. Reliability of chemical feed systems should be considered, and full redundancy is required in any feed system which is needed for the provision of safe drinking water. Applications that can influence primary disinfection should be installed with capability to respond to real-time sensing of flow failure, or have monitoring of actual flow to automatically trigger the redundant feed system or shutdown the process. The standby units should have sufficient capacity to replace the duty units.

The design of chemical feed systems should incorporate suitable drains, flushing line adapters and other necessary appurtenances to enable safe flushing of hazardous chemicals to facilitate maintenance.

Overflow/overpressure relief systems should be piped back to the original storage tank.

Materials and surfaces resistant to the potential for corrosion by the chemical should be selected.

Where there is potential for chemical interactions between streams that may reduce their effectiveness, or cause a degradation of water quality or other harmful health and safety effects, chemicals should be conducted from the feeder to the point of application in separate conduits. Chemical feeders should be located as near as possible to the feed point. All chemical feed systems should be equipped with a means such as a graduated tube to allow calibration of the feed equipment.

Care should be taken to avoid the use of diffusers and static mixers with chemicals which form scale or other solids. Frequently used chemicals that can produce scale in hard water include sodium hypochlorite, ammonia, sodium silicate, sodium aluminate, sodium hydroxide (caustic soda), phosphate and polyphosphate blends, sodium carbonate (soda ash) and calcium hydroxide (lime). This is especially important where variable flow rates can be expected as this greatly reduces mixing power levels produced with static mixing arrangements. Reliance should be placed instead on ensuring high local turbulence through creating a permanent high velocity of the main stream and/or by using high velocity softened dilution/carrier water streams. For chemicals that undergo especially rapid interactions on contact with water such as coagulants, the use of power mixers is preferred in order to ensure rapid dispersion of the chemical. The mixing of coagulants is specifically addressed in *Section 6.4.1 – Coagulation/Flocculation Chemicals*.

6.2 FACILITY DESIGN

6.2.1 General Storage & Handling of Chemicals

Storage for at least thirty days consumption at the maximum anticipated chemical usage rate should be provided, allowing for variations in chemical dosage and flow in that period. Where deliveries of chemicals can be expected to be interrupted by adverse weather conditions or in isolated locations, provision should be made for increased storage capacity. Where deliveries at short notice can be ensured, and the material is not essential to the production of safe water, storage requirements may be reduced.

Except where impractical in case of small water systems or where significant decay in chemical quality may be expected, sufficient storage should be provided to permit full load deliveries. The minimum recommended storage for truckload delivery is 1 ½ truck loads, or one truckload plus the quantity of chemical consumed in seven days, whichever is greater.

All chemical storage areas should be designed for containment of chemical spills. The minimum containment should be equal to 110% of the volume of the largest storage unit, or combination of units if interconnected, less the volume remaining in the container(s). Consideration of common header design and isolation for multiple tank installations should be made with respect to spill containment. Dissimilar chemicals should not share the same containment area. Containment walls should not be tied to the building walls, especially where floating slabs are used. Containments should undergo documented testing to demonstrate that they are leak proof.

Chemical or other process residuals should be handled in accordance with the requirements of *Chapter 11 – Waste Residuals Management*.

Storage of chemicals inside buildings is recommended to avoid problems of materials freezing or becoming too viscous to pump, vandalism, high costs of providing fully weatherproof equipment, and the difficulty of containing gaseous spills.

The chemical storage area should be segregated from the main areas of the treatment plant, and separate storage areas should be provided for each chemical. Where chemicals in storage could react dangerously with other materials in storage (e.g., chlorine and ammonia, strong acids and bases, oxidants and fuels) segregated storage is required. The storage and feed equipment areas should be arranged for ease of restocking of chemicals, process operation and monitoring.

Off-loading areas should be clearly labeled to prevent accidental cross-contamination. Chemicals should be stored in covered or unopened shipping containers, unless the chemical is transferred into a storage unit made of NSF/ANSI certified materials. Bags, fibre drums and steel drums should be stored on pallets.

All chemical storage should be at or above the surrounding grade. Where sub-surface locations for chemical storage tanks are proposed, these locations should be free from sources of possible contamination, assure positive drainage for ground waters and provide for containment of chemical spills and overflows. Where above grade storage is provided, due consideration should be given to the method of unloading chemicals; for example, there is a limit on the allowable pressures to be used for air-padded trucks. Where drums or dry bagged chemicals are used, a loading dock or ramp should be provided.

Storage areas should be arranged to avoid and contain chemical spills, or liquid from clean-up operations, from entering the water under treatment. Floor surfaces should be smooth and impervious, slip-proof, and sloped so as to drain rapidly. Drains should be equipped with a normally closed valve to prevent accidental discharge of spilled substances.

When necessary, ventilation systems should be arranged so that air is exhausted outside the building and slight negative pressures are maintained where dry chemicals are in use as a dust control measure. Where large amounts of dust are anticipated, appropriate local exhaust systems and filters, scrubbers or dust separators should be provided in the ventilation system. Ventilation systems should be designed specifically for use in a corrosive environment and special measures taken in dust systems to prevent static build-up or explosion potential.

The designer should note that special precautions may be necessary in the design of air emissions control systems to prevent chemical concentrations at the point of impingement from exceeding limits permitted within the building or site under *Air Pollution - Local Air Quality Regulation* (O. Reg. 419/05), made under the *Environmental Protection Act* (EPA), or which might be hazardous. An approval under Section 9 of the EPA is required if a contaminant may be discharged into the air in the course of normal operation. For details, see the ministry document *Guide for Applying for Approval (Air and Noise)* (PIBS 4174e).

Chemical buildings or storage areas must be provided with eye-wash and/or deluge showers, adequate facilities for cleaning up chemical spills, space for cleaning and storage of the recommended protective equipment.

All doors in chemical buildings should open outward, and corridors or space between storage areas should be a minimum 1.5 m (5 ft) wide to permit the use of hand trucks or other equipment for safe movement of materials.

Carts, elevators and other appropriate mechanical means should be provided for lifting chemical containers to minimize excessive lifting by operators.

Where chemical solutions are prepared in batches by the operator, provision should be made for measuring quantities of chemicals used to prepare the feed solutions. For liquid chemicals, graduated cylinders or other calibrated containers, transfer pumps, load cells for use under storage tanks and flow meters should be provided. For dry chemicals weigh scales, volumetric feeders, calibrated solution tanks and flow meters should be provided.

6.2.2 Safe Handling Considerations

Chemical buildings or storage areas must be provided with adequate warning signs, conspicuously displayed where identifiable hazards exist, and a storage area for filing *Material Safety Data Sheets* (MSDS) as set out under the federal *Hazardous Products Act* and associated *Controlled Products Regulations*. An MSDS must be available for each chemical. All storage containers should be conspicuously labeled in accordance with the *Workplace Hazardous Materials Information System* (R.R.O. 1990, Regulation 860) under the *Occupational Health and Safety Act* (OHSA).

The WHMIS label includes: the product name, the supplier name, hazard symbol(s), risk, precautionary measures and first aid measures.

6.2.3 Liquid Chemicals

6.2.3.1 Fill Line

All storage tanks should be provided with an adequately sized fill line, minimum 50 mm (2 in) in diameter, sloped to drain into the tank. The fill line should be properly identified at the end remote from the tank, and provision should be made to drain this fill line.

6.2.3.2 Vent

Each tank should have an adequate vent line, minimum size 50 mm (2 in), with a down-turned end. Where venting outside is required, the vent should be provided with an insect screen. Securing vents that are externally accessible should be considered to minimize potential for contamination of the tank contents. The potential for moisture build-up resulting in vent freezing should also be considered.

6.2.3.3 Overflow

All tanks should have an overflow appropriate for the rate of fill proposed for the tank, sloped down from the tank, with a down-turned end and free discharge, located where it can be readily observed, within the containment area. Overflow pipes should not connect directly to the sewer and an air gap to prevent backflow/ siphonage should be provided.

6.2.3.4 Drain

Each tank should be provided with an accessible, valved drain, which should not discharge directly to a sewer, and should terminate at least two pipe diameters above the overflow rim of a receiving sump.

6.2.3.5 Level Indicator

Each tank should be provided with means to indicate the level of liquid in the tank, and where an external level gauge is provided, a shut-off valve at the tank connection is recommended. Low level and high level alarms, enunciated where an operator is present, should be provided for process chemical day tanks, where applicable.

6.2.3.6 Covers

Tanks should be provided with removable lids or covers where the contents are such that venting indoors is permitted. In the case of tanks which are to be vented outside, the covers should be constructed so as to be air tight, or with a slow stream continuously exhausted.

6.2.3.7 Lined Tanks

Where lined tanks are proposed, weep holes in the outer shell should be provided to give an indication of liner leakage.

6.2.4 Dry Chemicals

6.2.4.1 Dust

Granular materials are preferred to powders. Particular care should be taken to protect mechanical and electrical equipment from fine dust. Where exhaust fans, filters, and conveying systems are used, grounding should be provided to prevent the build-up of static electricity.

Floor drains should be provided for wash down of floors in the transfer/storage area.

6.2.4.2 Bulk Storage Silos & Feeders

Bulk storage silos should be provided with adequately sized fill openings. Fill lines, where necessary, should be smooth internally with long radius elbows. Silos should be provided with suitable level indicating devices, such as load cells. They should include a pressure relief valve when pneumatic fill systems are provided. Silo vent and exhaust systems should be provided with dust filters and/or cyclone type separators to prevent the release of dust into the atmosphere. Air exhausted from the handling areas should be directed away from air intakes.

The designer should take into account material characteristics such as flowability, tendency to pack tightly, angle of repose in the design of the silo bottom and method of removal of material to a feeder. Provision should be made to relieve bridging or rat-holing of the stored material, either by manual, mechanical or other means of rapping or agitating the hopper bottom or improving flowability of the material, for example by air fluidization.

6.2.4.3 Transfer

Provision should be made for the transfer of dry chemicals from shipping containers to storage bins or hoppers, in such a way as to minimize the quantity of dust which may enter the room in which the equipment is installed. Dust control should be provided by use of vacuum pneumatic equipment or closed conveyor systems, facilities for emptying shipping containers in special enclosures and/or exhaust fans and dust filters which put the hoppers or bins under negative pressure.

6.2.4.4 Disposal

Provisions should be made for disposing of empty bags, drums or barrels by a procedure approved by the ministry which will minimize exposure to dust.

6.2.5 Gaseous Chemicals

6.2.5.1 Storage Areas

Gas storage areas should be separated from the other areas, with separate outside accesses, and arranged to prevent the uncontrolled release of spilled gas to other areas of the plant and surrounding environment.

6.2.5.2 Measuring Contents

Means of measuring the contents of gas containers should be provided, and where necessary for the proper operation of the feed system, means of adjusting and indicating gas pressure/vacuum and flow rates should be provided. A system for automatic changeover (for disinfection related gases) when gas cylinders are empty is required.

6.2.5.3 Feed Rates

Where high feed rates are required by evaporation from liquefied gas, it may not be possible to withdraw the required gas quantity from a single cylinder due to evaporative cooling and the consequent reduction in gas vapour pressure. The designer should consider either using multiple cylinders on-line or the use of an evaporator to meet higher withdrawal rates.

6.2.5.4 Moving Cylinders

The designer should allow sufficient space in the storage area for convenient moving of cylinders from full storage to on-line to empty storage.

For chlorine, sulphur dioxide, ammonia and carbon dioxide gas systems, the designer is referred to the Chlorine Institute and gas equipment suppliers.

6.2.6 Chemical Feed Equipment & Control

The design and capacity of feed equipment should be such that it can supply the required quantity of chemicals at a continuous rate. Equipment should be capable of proportioning the chemical feed rate to flow, and dosage adjustments should be available through the anticipated ranges of both dosage and water flow. This requirement may not apply to installations where flow is essentially constant. As a minimum, the additive flow rate should be within plus or minus 10% of the optimum flow rate over the full range of expected water flow rates.

Feeders may be either manually controlled or automatically controlled with manual override. Feed systems should be equipped with means to confirm delivery rate. As a minimum, calibration tubes should be provided. For more critical applications, continuous flow failure sensing or delivered volume confirmation should be provided, including alarms and where appropriate, capability for automatic shutdown.

Continuous monitoring equipment should be provided for critical processes and as required by O. Reg. 170/03. Sample locations and the configuration of the sampling system should be representative of the actual conditions. Issues relating to reaction time and proper mixing should be considered.

Dosing devices should be appropriate for the chemical feed range and the precision needed. Continuous feed (avoiding pulsed feed with time delays between pulses which are significant in relation to pulse duration) is required when the chemical application is required for an immediate chemical reaction, as in the application of chlorine and sodium silicate for sequestering. Special consideration should be given when selecting equipment for very small dosing systems.

All positive displacement pumps should be equipped with adequately sized pressure relief valves. If the pumped fluid is relieved through this valve, it should pass to a safe location, preferably back to the storage tank. Where liquid filled diaphragm pumps are in use, the over-pressure should be relieved by discharge of the motive fluid to a safe location. Where oil-filled diaphragm pumps are used, the oil must be of a grade suitable for use in drinking water supplies (food grade). Pressure relief valves should be set not greater than 20 per cent higher than the pump discharge pressure in normal operation. Double diaphragm pumps are recommended for corrosive chemical pumping. Positive displacement rotary pumps should be used for chemical slurries.

Turndown capability should be considered when specifying pump capacity. If necessary, higher ***turndown ratios*** can be achieved through independent adjustment of motor speed and stroke length or application of drives that vary motor speed during the stroke cycle to adjust capacity. Multiple pumps should be considered where demand or flow varies widely.

Where reciprocating type pumps are in use, flexible connections should be provided on the pump suction and discharge to prevent the transmission of vibrations to the feed line. These flexible sections should be sufficiently rigid to withstand both the pump suction and discharge pressures, and reinforced hose is recommended.

The pump, in combination with its suction piping and valving arrangement, should be such that the pump discharge rate is not affected by fluctuations in storage tank level or a suction line calibration tube.

Volumetric or gravimetric feeders are suitable for dry chemicals and should provide effective means of dissolving or dispersing the material prior to addition to the water under treatment.

The use of remote ejectors and transmission under vacuum is recommended for gaseous chemicals to avoid pressurized lines passing through the plant.

Where solution tanks are in use, means should be provided to maintain a uniform strength solution and continuous agitation should be provided to maintain slurries in suspension. Make-up water for the solution tank should enter the tank with an air gap providing a complete physical separation [not less than 150 mm (6 in) or two pipe diameters, whichever is greater] between the free flowing discharge end and the flood level of an open tank, unless the make-up water supply has an approved backflow preventer.

Where the design of the chemical feed system includes day tanks, consideration should be given to the decay of the chemical, whether the chemical will be diluted and the decay rate of diluted solution. Sizing of day tanks should also consider the level of staffing (i.e. 24-hour operation) and the degree of automation. A single day tank providing 72 hours of chemical storage may be appropriate for hypochlorite storage at small waterworks where the combination of needed dilution and storage time combined with available space would make the duplication of storage tanks unnecessary.

Day tanks should either be scale mounted or have a calibrated level gauge. The piping arrangement for refilling the day tanks should be such that it will prevent over-filling of the tanks. In all other respects the requirements for day tanks should conform to the requirements for larger storage tanks.

Chemical feed lines should be kept as short as practical, especially suction lines, protected from freezing, and located to be readily accessible. Feed lines should be sized in accordance with flow. Chemical feed lines discharging to a pressurized system should be equipped with a backflow prevention device just upstream of the chemical injection point to prevent back-mixing. Consideration should be given to solution feed lines that empty during zero process flow conditions (if the solution feed point is at a higher elevation than the application point and drains out by gravity). The designer should also consider the potential formation of scale and gas bubbles when sizing feed lines.

The designer should allow for line flushing and chemical cleaning where hard water supplies, which could promote scaling, are used in solution preparation. Consideration may also be given to flexible lines in a carrier pipe which can be easily replaced.

Where chemical strainers are employed, the design should allow for easy cartridge removal, as particulate from liquid chemical storage may impact feed pump functionality.

Where feed lines are provided from multiple feeders or distributed to multiple application points, adequate valving should be provided to isolate appropriate sections of the supply system.

6.2.7 Chemical Application Points

Potentially corrosive chemicals should not be applied immediately preceding screens or pumping equipment, nor should solids-producing materials be applied prior to pumping. Thorough and timely mixing of chemicals into the water flow may be critical in many cases, and application points should be through a suitably designed diffuser or selected for high turbulence. The designer should be aware of the potential for the accumulation of scale or other solids on the diffuser and should make provision for its removal and cleaning. Application points should not be located where water flow splits. Chemical application points should take into account deposition due to interactions with the flow stream that may block the application ports.

The sequence of addition of chemicals should be evaluated for potential interactions (reactions) that may decrease or eliminate the intended process effect. For example, the use of activated silica and alum for coagulation will have more successful results if the activated silica is added downstream of the alum, but would be ineffective if both are added at the same time since they react together.

Backflow or siphonage between multiple feed points should be prevented. Where chemicals are added to pressurized lines, isolating valves should be provided.

6.2.7.1 Fluoride

The conventional application point for fluoride solutions is in filter effluent lines or in the clearwell. At plants using well supplies, it is usually advantageous to inject the solution into the discharge side of the well pump. The application point of hydrofluosilicic acid, if in a pipe, should be in the lower half of the pipe. Fluoride should be added downstream of the application point(s) of any coagulant, coagulant aid and/or softening chemicals, lime-soda softening or ion exchange softening processes. The designer should take into account the aggressive action of hydrofluosilicic acid (if used) on concrete structures at the point of application.

6.2.7.2 Chlorine

The designer should consider the potential formation of disinfection by-products when selecting chlorine application points. For minimizing disinfection by-product formation, chlorine should be applied as far downstream in the treatment process as possible or practical. Pre-chlorination may not provide reliable disinfection with low quality raw water. The designer should also refer to applicable regulations and procedures for more information regarding disinfection requirements.

If chlorine is to be piped to a pre-oxidation point in the plant intake (for zebra mussel control or other reasons), the transport pipe should be located within the intake pipe and precautions should be in place to prevent leaks.

6.2.8 In-plant Water Supply

In-plant water supply should be designed to satisfy treatment plant water demand and pressure needs. Means for measurement should be provided when preparing specific solution concentrations by dilution. Treatment for hardness should be considered for the water supply, due to the scale-forming potential of mixing alkaline chemicals with hard water. The water supply should be obtained from a location sufficiently downstream of any chemical feed point.

Where service water is used for ejector feed pressure regulation, the design should allow for impacts from fluctuating pressures on critical chemical feed systems that require steady service water delivery for accuracy of chemical application.

6.2.9 Backflow Prevention/ Cross-Connection Control

Backflow or siphonage protection and cross-connection control should be incorporated for all applicable chemical feed systems. The service water lines discharging to solution tanks should be protected from backflow. Provisions should be made to ensure that liquid chemical solutions cannot be siphoned through solution feeders into the water supply. The in-plant water supply should be protected against backflow by a reduced pressure principle backflow preventer on pressurized lines or by an air gap in other applications. No direct connection should exist between any sewer and a drain or overflow from the feeder, solution chamber or tank. The designer should refer to the Canadian Standards Association (CSA) standards *CAN/CSA-B64 SERIES-01 Backflow Preventers and Vacuum Breakers, CAN/CSA-B64.10-01/B64.10.1-01 Manual for the Selection and Installation of Backflow Prevention Devices/Manual for the Maintenance and Field Testing of Backflow Prevention Devices,* and *B64.10S1-04/B64.10.1S1-Supplement #1 to CAN/CSA-B64.10-01/CAN/CSA-B64.10.1-01,* the AWWA *Manual of Water Supply Practices M14 – Recommended Practice for Backflow Prevention and*

Cross-Connection Control and USEPA *Cross-Connection Control Manual*, 2003.

6.3 OPERATOR SAFETY

6.3.1 Legislation & Regulations

The safety of workers and workplaces is governed by the *Occupational Health and Safety Act* (OHSA) and the *Workplace Safety and Insurance Act* (WSIA), as well as the regulations made under these acts. The design of water systems must include provisions to protect operator and other worker safety and health. For further information, consult the Act and regulations, specifically the *Industrial Establishments* (R.R.O 1990, Regulation 851) and the *Workplace Hazardous Materials Information System* (R.R.O. 1990, Regulation 860) regulations made under the *Occupational Health and Safety Act* (OHSA). The design of water systems should also take into consideration other applicable regulations such as building, electrical and fire codes.

6.3.2 Protective Equipment

Personal protective equipment should be provided for operators handling chemical compounds as required by applicable health and safety legislation. Deluge showers and eye wash stations should be provided where appropriate.

6.4 SPECIFIC CHEMICALS

6.4.1 Coagulation / Flocculation Chemicals

Rapid mixing should be provided for all systems which utilize chemical addition in the form of coagulation and flocculation in the treatment process. Agitation may be provided through mechanical in-line mixers, static mixers or paddle-type mechanical agitators.

Chemicals injected to rapid mix units should be injected at a point close to the inlet of the rapid mix unit. Coagulant/flocculant aids should not be injected into the rapid mixing unit unless an additional rapid mixing unit for the coagulant/flocculant aid is provided. Coagulant and coagulant/flocculant aid addition should be derived from jar and/or pilot testing.

In-line static mixers are recommended for rapid mixing of primary coagulants, provided that the flow is mainly constant and near the design maximum flow rate; alternatively, powered mixers should be used. Primary coagulants should not be mixed using in-line devices such as pumps, weirs, valves or other such appurtenances, as they do not provide controlled mixing. High intensity mixing reduces the performance of coagulant aids, and these should be added only with low shear mixing after a delay period of ideally one or two minutes.

6.4.2 Chlorine Gas

All chlorination facilities should be designed according to the recommendations of the Chlorine Institute (http://www.chlorineinstitute.org). Chlorine gas (Cl_2) feed and storage should be enclosed and separated from other operating areas. The chlorine room should be provided with a shatter resistant inspection window installed in an interior wall, constructed in such a manner that all openings between the chlorine room and the remainder of the plant are sealed, and provided with doors equipped with panic hardware, assuring ready means of exit and opening outward only to the building exterior.

Full and empty cylinders of chlorine gas should be isolated from operating areas, restrained in position to prevent upset and stored in rooms separate from ammonia storage. Cylinders should not be stored in areas exposed to direct sunlight or excessive heat.

Where chlorine gas is used, the room should be constructed to provide the following:

- Each room should have ventilation sufficient to produce 30 air changes per hour under emergency conditions and three air changes per hour under normal conditions when the room is occupied; where this is not appropriate due to the size of the room a lesser rate may be considered
- The ventilating fan should take suction near the floor as far as practical from the door and air inlet, with the point of discharge so located as not to contaminate air inlets to any rooms or structures;
- Air inlets should be through louvers near the ceiling;
- Louvers for chlorine room air intake and exhaust should facilitate airtight closure;
- Separate switches for the fan and lights should be located outside of the chlorine room and at the inspection window. Outside switches should be protected from vandalism. A signal light indicating fan operation should be provided at each entrance when the fan can be controlled from more than one point;
- Vents from feeders and storage areas should discharge to the outside atmosphere, above grade;

- The room location should be on the prevailing downwind side of the building away from features such as entrances, windows, louvers and walkways;
- Floor drains are discouraged. Where provided, the floor drains should discharge to the outside of the building and should not be connected to other internal or external drainage systems; and
- The need to install an absorption scrubber or any other device should be evaluated by the designer based on the site specific conditions including: volume of chlorine storage, type of containers, rate of chlorine gas withdrawal, and distance to public buildings or to the nearest point of impingement. The designer should consider the release of chlorine gas via safety relief systems to the environment. The design of absorption scrubbers should be based on environmental protection criteria rather than personnel safety criteria or facility protection. Confinement and local adsorption is an alternative that may also be considered.

Chlorinator rooms should be heated to 15°C (59°F) and be protected from excessive heat. Cylinders and gas lines should be protected from temperatures above that of the feed equipment. Pressurized chlorine feed lines should not carry chlorine gas beyond the chlorinator room.

6.4.2.1 Chlorination Equipment

Solution feed gas chlorinators or hypochlorite feeders of the positive displacement type should be provided.

The chlorinator capacity should be such that a free chlorine residual of at least 2 mg/L can be maintained in the water after a contact time of at least 30 minutes at the anticipated maximum flow rate. The equipment should be designed to ensure that it will operate accurately over the desired feeding range.

Standby equipment of sufficient capacity should be available to replace the largest unit. Spare parts should be made available to replace parts subject to wear and breakage. If there is a large difference in feed rates between routine and emergency dosages, a gas metering tube should be provided for each dose range to ensure accurate control of the chlorine feed.

Automatic switch-over of chlorine cylinders is needed to ensure continuous disinfection.

Automatic proportioning chlorinators are recommended where the rate of flow or chlorine demand varies by more than plus or minus 10%.

Each eductor should be selected for the point of application with particular attention given to the quantity of chlorine to be added, the maximum injector water flow, the total discharge back pressure, the injector operating pressure and the size of the chlorine solution line. Gauges for measuring water pressure and vacuum at the inlet and outlet of each eductor should be provided.

The chlorine solution injector/diffuser should be compatible with the point of application to provide a rapid and thorough mix with all the water being treated. The centre of a pipeline is the preferred application point.

The chlorinator water supply piping should be designed to prevent contamination of the treated water supply by sources of questionable quality. At all facilities treating surface water, pre- and post-chlorination systems should be independent to prevent possible siphoning of partially treated water into the clearwell. The water supply to each eductor should have a separate shut-off valve. Master shut-off valves are not recommended.

The pipes carrying liquid or dry gaseous chlorine under pressure, as well as all chlorine solution piping and fittings, must be constructed of materials recommended by the Chlorine Institute. Nylon products are not recommended for any part of the chlorine solution piping system.

6.4.3 Sodium Hypochlorite

Sodium hypochlorite storage and handling procedures should be arranged to minimize decay either by contamination or by exposure to more extreme storage conditions. In addition, feed rates should be regularly adjusted to compensate for this progressive loss in chlorine content.

Sodium hypochlorite should be stored in the original shipping containers or in sodium hypochlorite compatible containers. Storage containers or tanks should be sited out of the sunlight in a cool area and vented to the outside of the building.

Wherever reasonably feasible, stored hypochlorite should be pumped undiluted to the point of addition. Where dilution is unavoidable, deionized or softened water should be used. Injectors should be selected to be resistant to scale blockage or should be made removable for regular cleaning where hard water is to be treated. For small ground water supplies which are typically served by a hypochlorite metering pump controlled by the well pump in an on-off operation, the dilution of hypochlorite to lower concentrations may be necessary for proper operation of a regular diaphragm metering pump unless a small volume dosing system is used.

Pipe system design should allow for adequate flushing of components primarily for operator/maintenance personnel safety considerations.

Storage areas, tanks and piping should be designed to avoid the possibility of uncontrolled discharges, and a sufficient amount of appropriate spill absorbent should be stored on-site.

Reusable hypochlorite storage containers should be reserved for use with hypochlorite only and should not be rinsed out or otherwise exposed to internal contamination.

Positive displacement pumps with hypochlorite compatible materials for wetted surfaces should be used. To avoid air locking in smaller installations, small diameter suction lines should be used with foot valves and degassing pump heads. In larger installations, flooded suction should be used with piping arranged to ease escape of gas bubbles.

6.4.3.1 On-Site Generation of Sodium Hypochlorite

Proprietary equipment is available for the production of dilute hypochlorite solution by electrolysis of sodium chloride brine. The design should provide for a supply of softened water for brine makeup in order to protect the electrode life and to safely discharge an off-gas stream of hydrogen. A day tank for storage of the hypochlorite solution should also be provided. This process may be more advantageous in remote locations where transportation/delivery is an issue. The designer should consult the manufacturer for specific design requirements.

6.4.4 Chlorine Dioxide

Chlorine dioxide gas, even in mixtures of over 10% in air, is highly unstable and as a result, it must be generated on-site. The gas should be handled only in water solution with feed lines arranged to avoid gas pocket formation, be maintainable under moderate pressure and be easily water purged. The gas is toxic; therefore, the designer should make appropriate provisions to protect operations staff from excessive exposure.

6.4.4.1 Chlorine Dioxide Generators

Chlorine dioxide generation equipment should be factory assembled and pre-engineered units with a minimum efficiency of 95%. The excess free chlorine should not exceed 3% of the theoretical stoichiometric concentration required.

Common continuous generators require a stream of sodium chlorite solution and a carefully proportioned stream of chlorine. Where chlorine is not available, hypochlorite solution and an acid may be used in a three-feed reactor. When feed streams are correctly proportioned, these generators can show an efficiency in generating chlorine dioxide of over 95%.

A variant generator that uses only hydrochloric acid and chlorite solution is simpler to feed but operates at lower conversion efficiency. It produces chlorine dioxide that does not contain any elemental chlorine contamination; as a result it does not form any THMs or HAAs when used as a disinfectant.

The design of chlorine dioxide equipment should conform to all applicable design criteria relating to chlorination equipment (*Section 6.4.2.1 – Chlorination Equipment*) as well as to the manufacturer recommendations.

6.4.5 Sodium Chlorite

Sodium chlorite is used for chlorine dioxide generation. Chlorite may also be effective in inhibiting nitrifying bacterial activity in some chloraminated distribution systems.

Sodium chlorite is available in concentrated solution or granular form. The liquid form is preferred for ease of handling.

Sodium chlorite should be stored by itself in a separate room and preferably in an outside building detached from the water treatment facility. It should be stored away from organic materials because many materials may catch fire and burn violently when in contact with chlorite.

The storage structures should be constructed of non-combustible materials. If the storage structure must be located in an area where a fire may occur, water should be available to keep the sodium chlorite area cool enough to prevent explosion. The design should take into consideration explosion proof equipment requirements (if applicable).

Positive displacement feeders should be provided. Tubing for conveying sodium chlorite or chlorine dioxide solutions should be Type 1 PVC, polyethylene or materials recommended by the manufacturer.

Where appropriate, check valves should be provided to prevent the backflow of chlorine into the sodium chlorite line.

6.4.6 Ammonia

Production of monochloramine for secondary disinfection can be achieved by the addition of ammonia or ammonium salts, usually to prechlorinated water streams. Correct proportioning and effective mixing are required to avoid the formation of odorous dichloramines and trichloramines. Care should also be taken to avoid operating at the breakpoint, where there may be no residual chlorine. Ammonia for chloramine formation may be added to water either as a water solution of ammonium sulphate, as aqua ammonia (ammonium hydroxide), or as anhydrous ammonia (purified ammonia in liquid or gaseous form). Special provisions required for each form of ammonia are listed below. The designer should consult with the chemical manufacturer/supplier regarding additional specific requirements for handling, storage and feeding. Continuous gentle extractive ventilation of the ammonia area is advised to protect copper wiring and other metallic items from accelerated corrosion.

6.4.6.1 Ammonium Sulphate

A water solution is made by mixing ammonium sulphate solid with water. The tank and dosing equipment contact surfaces should be made of corrosion resistant non-metallic materials. Provision should be made for removal of the agitator after dissolving the solid. The tank should be fitted with a lid and vented outdoors. AWWA *Standard B302: Ammonium Sulfate* provides additional safety, handling and storage information.

6.4.6.2 Aqua Ammonia

Ammonia solutions may be obtained from suppliers at concentrations under 20% w/w. This more dilute product minimizes the ammonia vapour pressure over the liquid and the associated handling difficulties. Aqua ammonia feed pumps and storage should be enclosed and separated from other operating areas.

The aqua ammonia should be conveyed directly from storage to the injector without the use of a carrier water stream unless the carrier water is softened. Provision should be made for easy access for removal of scale deposits from the injector.

The designer may consider the installation of a small capacity scrubber capable of handling occasional ammonia emissions which may occur during tank filling.

6.4.6.3 Anhydrous Ammonia

Anhydrous ammonia is readily available as a pure liquefied gas under moderate pressure in cylinders or as a cryogenic liquid boiling at -15°C (5°F) at atmospheric pressure. The liquid causes severe burns on skin contact.

Anhydrous ammonia and storage feed systems (including heaters where required) should be enclosed and separated from other works areas and constructed of corrosion resistant materials. Pressurized ammonia feed lines should be restricted to the ammonia room.

An emergency air exhaust system, with an elevated intake, should be provided in the ammonia storage room. Leak detection systems should be fitted in all areas through which ammonia is piped.

Special vacuum breaker/regulator provisions should be made to avoid potentially violent results of backflow of water into cylinders or storage tanks.

Carrier water systems of soft or pre-softened water are essential for transporting ammonia to the finished water stream and to assist in mixing. The ammonia injector should use a vacuum eductor or should consist of a perforated tube fitted with a closely fitting flexible rubber tubing seal punctured with a number of small slits to delay fouling by lime deposits. Provision should be made for the periodic removal of scale/lime deposits from injectors and carrier piping.

Where storage units are housed in enclosed areas, consideration should be given to the provision of an emergency gas scrubber capable of absorbing the entire contents of the largest ammonia storage unit whenever there is a risk to the public as a result of potential ammonia leaks.

6.4.7 Chemicals Used in Dechlorination Facilities

Dechlorination is practiced to partially or totally remove chlorine residual. The most commonly used reducing agent is sulphur dioxide. Other common dechlorination chemicals include sodium sulphite, sodium bisulphite, sodium metabisulphite, sodium thiosulphate and hydrogen peroxide. Table 6.1 shows the theoretical amount of each dechlorination chemical needed to remove one part of chlorine residual.

Table 6-1: Dechlorination Chemicals & Theoretical w/w Ratios

DECHLORINATION CHEMICAL	PART(S) REQUIRED TO DECHLORINATE ONE (1) PART Cl2
Sulphur Dioxide	0.90
Sodium Sulphite	1.80
Sodium Bisulphite	1.52
Sodium Metabisulphite	1.33
Sodium Thiosulphate	7.00
Hydrogen Peroxide	0.48

Gaseous storage facilities may house gaseous sulphur dioxide for dechlorination requirements. Most precautions for gaseous chlorine (*Section 6.4.2 – Chlorine Gas*) will also apply for sulphur dioxide. The designer should consult the manufacturer for specific details regarding storage and handling requirements for sulphur dioxide and other reducing agents used for dechlorination.

Guidance on dechlorination can be found in the AWWA Manual of Water Supply Practices M20 – Water Chlorination/Chloramination Practices and Principles, and the AwwaRF report Guidance Manual for Disposal of Chlorinated Water (Project #2513).

6.4.8 Acids & Bases

Strong acids and bases should be stored in separate areas. Concentrated acids and bases should be kept in closed corrosion-resistant shipping containers or storage units. Acids and bases should not be handled in open vessels, but should be pumped in undiluted form from original containers through suitable hose to a dilution tank, or where dilution is not required to aid process control, to the point of treatment or to a covered day tank. Separate ventilation systems may be required for areas where concentrated acids or bases are stored.

6.4.9 Ozone

6.4.9.1 General

Ozone is an unstable and very powerful oxidant and needs to be generated electrically on-site.

For small systems, very simple, low maintenance pre-engineered treatment units producing ozone from ambient air at up to a very few grams of ozone per hour are used.

For taste and odour control, and for primary disinfection, larger outputs of ozone are generally required using proprietary equipment. The designer should consult the manufacturer for power, air-feed, cooling and temperature requirements, as well as contactor design and ozone destructor requirements. Additional guidance for the design of large scale ozonation systems is provided in the Ten States Standards.

High purity oxygen used as feed gas can be purchased and stored as a liquid (LOX), or it can be generated on-site through either a cryogenic process, vacuum swing adsorption (VSA) or pressure swing adsorption (PSA). Cryogenic generation of oxygen is a complicated process and should only be considered for large systems. Storage of LOX is governed by regulations in building and fire codes. These regulations will impact the space requirements and may dictate the construction materials of adjacent structures.

The generators can be low, medium or high frequency type. Specifications should require that the transformers, electronic circuitry and other electrical hardware be proven, high quality components designed for ozone service. Appropriate ozone generator backup equipment should be provided.

Only low carbon 304L or 316L grade stainless steel piping should be used for ozone service with 316L being the preferred material. Connections on piping used for ozone services should be welded, where possible. Connections with meters, valves or other equipment are to be made with flanged joints with ozone resistant gaskets, such as Teflon™ or Hypalon™. Screwed fittings should not be used because of their tendency to leak.

Ozone monitors should be installed to measure ozone concentration on both the feed gas and off-gas from the contactor and in the off-gas from the destruct unit. For disinfection systems, monitors should also be provided for monitoring ozone residuals in the water. The number and location of ozone residual monitors should be such that the amount of time that the water is in contact with the ozone residual can be determined.

A minimum of one ambient ozone monitor should be installed in the vicinity of the contactor and a minimum of one should be installed in the vicinity of the generator. Ozone monitors should also be installed in any areas where ozone gas may accumulate. Ambient ozone exposure levels are governed by the *Occupational Health and Safety Act* (OHSA).

6.4.9.2 Ozone Contactors

The specific process objective should dictate contact basin design. Reactions that are rapid relative to the ozone mass transfer rate from gas to liquid phase are best served by contactors that promote the maximum transfer of ozone in the shortest period of time. For these applications, such as oxidation or iron, manganese or simple organics, contact time is often less important and contactors that rely on single points of application may be suitable. For reactions that are slow relative to the ozone mass transfer rate, such as disinfection or oxidation of complex organics (such as herbicides or pesticides), contact time is critical and favours contactors with extended detention time and multiple application points, such as the conventional multi-stage fine bubble diffuser design.

The types of contactors that are commonly used include:

- Conventional fine bubble

- Turbine
- Packed column
- Injectors
- Deep U-tube

Bubble Diffusers

The most common design is a multichamber over-under baffled contactor with ozone addition to the first one or two chambers via diffusers situated at the bottom of the chambers. Where disinfection is the primary application, a minimum of two contact chambers each equipped with baffles to prevent short circuiting and induce counter-current flow should be provided. The water depth in the contactor is typically between 4.6 and 6 m (15 and 20 ft) to achieve high transfer efficiency of the added ozone.

Once the immediate or initial ozone demand has been satisfied and a residual ozone level has been maintained in contactor stages, the designer may consider the provision of a "passive" stage without ozone diffusers, which will serve to increase the required retention time without the cost of the additional diffusers and associated piping.

The contactor should be designed to ensure good flow dispersion and to avoid short-circuiting. The diffusion system should optimize liquid/gas contact and maximize mass transfer. For optimum ozone transfer efficiency, gas bubble size should be between 2 and 5 mm (0.08 and 0.2 in).

Ozone should be applied using porous tube or dome diffusers. For ozone applications in which precipitates are formed, such as with iron and manganese removal, porous tube diffusers are not recommended. Dome diffusers are generally preferred as they produce finer bubbles. Due to head loss limitations, proprietary diffusers typically have a maximum gas flow rating that should not be exceeded. The chamber floor area should therefore be large enough to accommodate the minimum number of diffusers.

Contactors should be separate closed vessels that have no common walls with adjacent rooms. The contactor should be kept under negative pressure and ozone monitors should be provided to protect worker safety. Placement of the contactor where the entire roof is exposed to the open atmosphere is recommended.

Large contact vessels should be made of reinforced concrete. All reinforcement bars should be covered with a minimum of 38 mm (1.5 in) of concrete. Smaller contact vessels can be made of stainless steel, fibreglass or other material which will be stable in the presence of residual ozone and ozone in the gas phase above the water level.

Multiple sampling ports should be provided to enable sampling of effluent water in each compartment and to confirm CT calculations.

Contactors should be designed with approximately 1 m (3 ft) of headroom to provide for unimpeded gas flow to the off-gas exit. Where necessary, a system should be provided between the contactor and the off-gas destruct unit to remove froth from the air and return the froth to the contactor or other acceptable location. If foaming is expected to be excessive, then a potable water spray system should be placed in the contactor head space.

All contactors should have provisions for cleaning, maintenance and drainage of the contactor. The basic arrangement of the contactor will establish the provisions required for personnel access. Stainless steel hatches with ozone-resistant gaskets should be provided for each contactor stage to minimize difficulty and delay of entry and exit from the contactor under regular and emergency conditions. The design should also provide for exhaust ventilation prior to the entry of maintenance personnel

Other Contactors

Other contactors may be acceptable, provided adequate ozone transfer is achieved and the required contact times and residuals can be met and verified.

6.4.9.3 Ozone Destruction Unit

A system for treating the final off-gas from each contactor should be provided in order to meet safety and air quality standards. Acceptable systems include thermal destruction and thermal/catalytic destruction units.

In order to reduce the risk of fires, the use of units that operate at lower temperatures is encouraged, especially where high purity oxygen is the feed gas.

The maximum allowable ozone concentration in the air discharge is 0.1 mg/L (by volume).

At least two units should be provided which are each capable of handling the entire gas flow.

Exhaust blowers should be provided in order to draw off-gas from the contactor into the destruction unit.

Heat exchangers and catalysts should be protected from froth, moisture and other impurities which may harm the units.

The catalyst and heating elements should be located where they can easily be reached for maintenance.

6.4.9.4 Alarms

The following alarms/shutdown systems should be considered at each installation:

- **Dew point shutdown/alarm** – This system should shut down the generator in the event the system dew point exceeds -60ºC (-76ºF);
- **Ozone generator cooling water flow shutdown/alarm** – This system should shut down the generator in the event that cooling water flow decreases to the point that generator damage could occur;
- **Ozone power supply cooling water flow shutdown/alarm** – This system should shut down the power supply in the event that cooling water flow decreases to the point that damage could occur to the power supply;
- **Ozone generator cooling water temperature shutdown/alarm** – This system should shut down the generator if either the inlet or outlet cooling water exceeds a certain preset temperature;
- **Ozone power supply cooling water temperature shutdown/alarm** – This system should shut down the power supply if either the inlet or outlet cooling water exceeds a certain preset temperature;
- **Ozone generator inlet feed gas temperature shutdown/alarm** – This system should shut down the generator if the feed gas temperature exceeds a certain preset value;
- **Ambient ozone concentration shutdown/alarm** – The alarm should sound when the ozone level in the ambient air exceeds 0.1 ppm or a lower value chosen by the municipality/owner. Ozone generator shutdown should occur when ambient ozone levels exceed 0.3 mg/L (or a lower value) either in the vicinity of the ozone generator or the contactor; and
- **Ozone destruct temperature alarm** – The alarm should sound when temperature exceeds a preset value.

6.4.10 Hydrogen Peroxide

Advanced oxidation processes using a combination of peroxide and ozone or peroxide and UV have been developed which require a hydrogen peroxide feed system and an ozone generation or UV system. For AOPs using ozone, hydrogen peroxide can be added upstream or downstream of ozone, or simultaneously. Where UV is used, peroxide is added either upstream or simultaneously with UV. Ozone generation systems are discussed in *Section 6.4.9 – Ozone*. Design considerations for UV systems are discussed in *Section*

5.9.5 – Ultraviolet Light Inactivation. Peroxide removal should be accomplished before the application of chlorine.

Peroxide is a strong oxidant and contact with personnel should be avoided. Secondary containment should be provided for storage tanks to contain any spills. Dual containment piping should be considered to minimize the risk of exposure to plant personnel.

Peroxide can be stored in high density polyethylene or 304L or 316L grade stainless steel drums or tanks. Peroxide can be stored on-site but deteriorates gradually over time. Peroxide deteriorates rapidly if contaminated and with heat or exposure to certain materials. Excessive heat may cause a tank rupture due to gas generation if the tank is not vented properly. Tanks should be vented according to the manufacturer/supplier specifications. Peroxide has a lower freezing point than water, however, housing or heat tracing should be provided for storage tanks and exterior piping if extended periods with temperatures below freezing are anticipated. Hydrogen peroxide, at concentrations of 35% and 50%, freezes at temperatures of -40°C (-40°F) and -45°C (-49°F) respectively.

Pipes, gaskets and metering pumps should be constructed of peroxide resistant materials. The designer should ensure that all wetted stainless steel components are passivated using industry accepted passivation procedures. Pumps should be designed to prevent potential air binding of peroxide off-gas. Adequate mixing should be provided. It is recommended that all peroxide chemical dosing systems be provided with safety relief valves in areas where hydrogen peroxide can become trapped.

6.4.11 Potassium Permanganate

Potassium permanganate solution decomposes slowly and, as a result, is better purchased as a granular solid. Potassium permanganate may be supplied in dry form in buckets, drums and bulk. A concentrated potassium permanganate solution (1 to 4%) can be generated on-site for water treatment applications. Depending on the amount of permanganate required, these solutions should be made up in batch modes, using storage tanks with mixers and a metering pump for small feed systems. Larger systems should include a dry chemical feeder, storage hopper and dust collector configured to automatically supply permanganate to the solution storage tank.

In conventional treatment plants, potassium permanganate solution is added to the raw water intake, or as far upstream of coagulant addition as possible. Adequate mixing should be provided. In all cases, potassium permanganate should be added prior to filtration.

Potassium permanganate solution should be pumped from the solution tank to the injection point. If the injection point is a pipe, a standard injection nozzle protruding midway into the pipe section should be used. Injection nozzles can also be used to supply the solution to mixing chambers and clarifiers. Powered activated carbon (PAC) and potassium permanganate should not be added concurrently. PAC should be added downstream of potassium permanganate because it may adsorb permanganate, rendering it unavailable for the oxidation of target organics.

6.4.12 Phosphates & Polyphosphates

Stock phosphate solutions should be kept covered and disinfected by maintaining approximately 10 mg/L chlorine residual. Phosphate solutions having a pH of 2.0 or less may be exempt from this requirement.

Polyphosphates should not be applied ahead of iron and/or manganese removal treatment. The point of application should be prior to any aeration, oxidation or disinfection if no iron or manganese removal treatment is provided.

Feed and storage equipment should conform to the requirements specified by the manufacturer.

6.4.13 Powdered Activated Carbon (PAC)

The designer should consider the possibility of powered activated carbon (PAC) addition at several points within the treatment process. PAC addition should take place as far upstream of coagulant addition as possible, preferably with mechanically aided mixing. The designer should avoid feeding chlorinated water to any form of carbon.

PAC can be added as a premixed slurry or by means of dry feed. Continuous agitation should be provided to ensure that the PAC does not deposit in the slurry storage tank.

PAC should be considered as a potentially combustible material and should be stored in a separate fire retardant building or room equipped with explosion proof lighting and electrical systems. Wet activated carbon may create an oxygen-deficient environment in enclosed spaces, therefore, appropriate safety precautions should be provided. The manufacturer recommendations regarding storage and handling should be followed.

Provision should be made for adequate dust control. Provisions should also be made to scrub or filter the carrier air when dry PAC is off-loaded into silos.

6.4.14 Fluoride

Sodium fluoride, hydrofluosilicic acid and sodium silicofluoride may be used for fluoridation. These compounds are highly corrosive and require specific considerations. In addition to these guidelines, the designer should refer to a fluoride manual such as AWWA *Manual of Water Supply Practices M4 – Water Fluoridation Principles and Practices*.

Water used for sodium fluoride dissolution should be softened if hardness exceeds 75 mg/L as calcium carbonate.

For smaller systems, the electrical outlet used for the fluoride feed pump should have a non-standard receptacle and should be interconnected with the well or service pump;

Saturators should be of the upflow type and be provided with a meter and backflow protection on the make-up water pipe.

Construction should be of corrosion resistant material. The use of explosion proof motors and electrical components should be considered. Light and fan switches should not be located within the fluoride room.

6.4.15 Carbon Dioxide

Where carbon dioxide is added for pH adjustment, the contact chamber should provide a detention time sufficient to ensure effective absorption. The recarbonation basin design should provide:

- A total detention time of 20 minutes;
- A minimum of two parallel compartments, with a depth that will provide a diffuser submergence of not less than 2.3 m (7.5 ft) nor greater submergence than recommended by the manufacturer, as follows:
  - A mixing compartment having a detention time of at least three minutes; and
  - A reaction compartment.
- The practice of on-site generation of carbon dioxide is discouraged;
- Where liquid carbon dioxide is used, adequate precautions should be taken to prevent carbon dioxide from entering the plant from the recarbonation process;

- Recarbonation tanks should be located outside or be sealed and vented to the outside with adequate seals and adequate purge flow of air to ensure worker safety; and

- Provisions should be made for draining the recarbonation basin and removing sludge.

CHAPTER 7

PUMPING FACILITIES

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CHAPTER 7

PUMPING FACILITIES

The requirements described in this chapter apply to raw and treated water pumping stations and booster pumping stations. Pumping facilities should be designed to maintain the quality of pumped water, for example, by minimizing retention time and ensuring adequate flows and velocities in the distribution system. Appropriate design measures to help ensure the security of water pumping facilities should also be incorporated (*Section 3.24 – Security*).

7.1 GENERAL

The design of the pumping station is also governed by a number of acts and regulations that do not fall under the jurisdiction of the ministry, including but not limited to Ontario Ministry of Labour regulations, building, electrical, and fire codes.

Groundwater well pumps and backwash pumping are discussed in *Chapter 4 – Source Development* and *Chapter 5 – Treatment*, respectively. Positive displacement pumps used for chemical pumping are discussed in *Section 6.2.6 – Chemical Feed Equipment and Control*.

7.2 STATION TYPES

The three types of pumping facilities addressed in this chapter are raw water pumping (commonly called low lift pumping), treated water pumping (commonly called high lift pumping) and booster pumping stations.

Pumping stations commonly use either horizontal centrifugal pumps, vertical turbine pumps or submersible pumps. Typically, horizontal splitcase centrifugal pumps are equipped with side suction and side discharge, while larger units may have bottom suction. Refer to the Hydraulic Institute (HI) *ANSI/HI Pump Standards* for appropriate uses of different pump types.

7.3 GENERAL DESIGN CONSIDERATIONS

7.3.1 Firm Capacity & Station Capacity

Raw water pumping stations should be provided with firm capacity, which is defined as:

- Capacity of the raw water pumping station able to supply the water treatment plant design capacity with the largest unit out of service.

Consideration should also be given to other circumstances such as distance from the water treatment plant and the availability of raw water storage.

Treated water and booster pumping stations should be provided with firm capacity, which is defined as:

- Capacity of the pumping station with the largest unit out of service if the station supplies a pressure zone with adequate storage available for fire protection and balancing. Sizing of storage facilities is discussed in *Section 8.4 – Sizing of Storage Facilities*; and

- Capacity of the pumping station with the two largest units (including the fire pump[s], if any) out of service if the pumping station serves a pressure zone that does not have adequate ***floating storage*** available and is the sole source of supply in the area.

Pumping station structures, major piping and appurtenances should be designed for at least the 20-year estimated flow or if practicable, for the ultimate service area requirements. Alternatively, the initial design should be such as to permit expansion to the ultimate capacity. The initial design should allow for additional pumping units, standby power facilities, transformers, and other mechanical, electrical and treatment equipment as will be required in future. Consideration should also be given to the potential consequences of over-sizing of the initial equipment, especially with respect to metering devices.

7.3.2 Site Considerations & Protection

System hydraulics, protection against interruption of service by fire, flood, freezing or any other hazard should also be considered during site selection.

The station should be elevated to a minimum of 1 m (3 ft) above the 100-year flood elevation, or 1 m (3 ft) above the highest recorded flood elevation, whichever is higher, or protected to such elevations, unless a hydraulic analysis is completed to identify a more appropriate elevation. Consideration should also be given to the requirements of the local Conservation Authority (http://conservation-ontario.on.ca/).

The station should be readily accessible at all times. To allow for servicing, vehicle access to the pumping station should be provided. The grade around the station should lead surface drainage away from the station. The distance from the pumping station exit, as well as the need for additional exits, is governed by the *Building Code* (O. Reg. 350/06) made under the *Building Code Act, 1992*. Protection to prevent vandalism and entrance by animals or unauthorized persons should be provided.

Pumping stations should have adequate space for the safe servicing of all equipment. Stations should be of durable construction, fire and weather resistant and have outward-opening doors. Where permitted by code, inward opening doors may be considered. Floor elevation should be at least 150 mm (6 in) above finished grade. The underground structure should be waterproofed. All floors should slope to a suitable drain and drain in such a manner that the pumped water will not be contaminated. Building drains should be constructed in such a way as to prevent any potential break or leakage from entering any ***wet well*** structure. Building drains should not be built within water bearing structures. Means for drainage from pump glands without discharging onto the floor should be provided. A sump pump should be supplied to ensure that any miscellaneous water entering the station is removed. Sump pump systems should be alarmed for flood conditions. A vent or a vent system should be provided for all process related structures (i.e., wet well). The vents should be equipped with a 180° bend with insect screen at the outlet. For vents on critical structures, the design should incorporate solid/liquid protection from entry into the vent by vandalism or sabotage.

If diesel or other fuelled engines are to be used for standby power, the requirements of Section 9 of the *Environmental Protection Act* (EPA)must be satisfied and an application for air approval may be necessary (*Section 3.13 – Emissions of Contaminants to Air*). If the isolation from the engine exhaust to the nearest point of impingement is not sufficient to dissipate the air contaminants to within the regulated levels, an exhaust stack may be required.

Any electrical controls, switch gear, or transformers located outside the pumping station should be properly housed and fenced in accordance with the local hydro requirements.

7.3.3 Pumping Wet Wells

The floor should be sloped to a sump for easy cleaning and draining. The well should be covered and protected from contamination. Well access routes should be adequately sealed against liquid penetration. A 100 mm (4 in) curb should surround any floor openings to prevent floor drainage entering the well and the well should be adequately vented. The wet well should be designed with two pumping compartments or other means to allow the well to be taken out of service for inspection, maintenance or repair, while still maintaining a portion of the station capacity in service.

The design of the wet well will depend substantially on the number, type and size of the pumps required. The design should conform to the recommendations of the Hydraulic Institute standard *ANSI/HI 9.8-1998 Pump Intake Design*.

7.3.4 Equipment Servicing

Minimum spacing around pumps, piping, and fittings should comply with the requirements of the *Building Code* (O. Reg. 350/06) made under the *Building Code Act, 1992*, and the *ANSI/HI Pump Standards*. Pumping stations should be provided with lifting devices such as crane-ways, hoist beams, eyebolts or other facilities for servicing or removal of pumps, motors, valves, piping or other heavy equipment without the need for heavy manual labour and with minimum disturbance to the system. Cranes and any other lifting devices should be rated to a capacity exceeding that of the heaviest equipment unit anticipated with an appropriate safety margin. Openings in floors, roofs or wherever else needed should be provided for removal of heavy or bulky equipment. Such openings should be designed to bear the loads of equipment traversing them.

A convenient tool board, or other facilities as needed, should be provided for proper maintenance of the equipment.

7.3.5 Stairways &d Ladders

Stairways or ladders should be provided between all floors and in pits or compartments which must be entered, or as required by the *Building Code* (O. Reg. 350/06) made under the *Building Code Act, 1992*.

Stairways or ladders should have handrails on both sides and treads of non-slip material. Stairs are preferred in areas where there is frequent traffic or where supplies are transported by hand. Stair and tread dimensions should conform to the requirements of the *Building Code* (O. Reg. 350/06) made under the *Building Code Act, 1992*.

Stainless steel may be considered for submerged conditions.

7.3.6 Heating, Ventilation & Dehumidification

Provisions should be made for adequate heating for the comfort of the operator and the safe and efficient operation of the equipment. For pumping stations not occupied by personnel, only enough heat need be provided to prevent freezing of equipment or treatment processes.

Ventilation should conform to existing local and/or provincial codes. Adequate ventilation should be provided for all pumping stations for operator comfort and dissipation of excess heat from the equipment. Forced ventilation of at least six changes of air per hour at the high fan speed and three changes of air per hour at the low fan speed (regular operation), and manual-off position should be provided for all confined rooms, compartments, pits and other enclosures below ground floor, as well as any area where unsafe atmosphere may develop or where excessive heat build up may occur.

In areas where excess moisture could cause hazards to safety or damage to equipment, means for dehumidification should be provided.

7.3.7 Lighting

Pumping stations should be adequately lighted throughout. Moisture resistant lighting should be considered. All electrical work is governed by the requirements of the *Electrical Safety Code*, (O. Reg. 164/99) under the *Electricity Act, 1998*. More information regarding electrical systems is provided in *Section 3.10 – Electrical Components*. Emergency lighting and illuminated exit signs should be provided at appropriate locations in case of power failure.

Provision of multiple lighting levels may also be considered for various duties, such as minimum lighting for walkthroughs and minor checks and high-level lights for major maintenance.

7.3.8 Sanitary & Other Conveniences

All pumping stations that are staffed for extended periods on a regular basis should be provided with potable water, lavatory and toilet facilities. Plumbing should be so installed as to prevent contamination of a public water supply. Sanitary wastes should be discharged in accordance with *Section 3.27 – Water Treatment Plant Residuals and Sanitary Waste*.

Eyewash and safety showers should be provided where potentially harmful chemicals are present in the pumping facility.

7.3.9 Controls

Pumps, their prime movers and accessories should be controlled to ensure that they will operate in such a manner that will prevent motor overload. Control systems should limit the number of start/stop sequences (according to the pump and electrical equipment manufacturer recommendations) and prevent coincidental simultaneous starting of numerous pumps. Where duplicate pumps are installed, provision should be made for alternation of service cycles. Provision should be made to prevent energizing the motor in the event of a backspin cycle. Electrical controls should be located above grade. Equipment should be provided, or other arrangements made, to prevent hydraulic surge pressure from activating controls which switch on pumps or activate other equipment outside the normal design cycle of operation.

The type of control for pump operation is an important consideration for pump specification and selection, and will depend on whether the pump(s) are part of an open or closed pumping system.

In closed systems (treated water, booster pumping), a control valve (not normally supplied by the pump manufacturer) should be provided to ensure proper operation of the pump. An air release valve should also be provided in the pump discharge to let the air out of the discharge pipe at pump start-up.

Pressure control is commonly used for pump operation in both open systems and closed systems. However, care must be taken for pump selection when this type of control is used as it can have a significant effect on the operation of a pump, specifically, the designer should aim to select a process pump characterized with a steep flow rate versus total dynamic head curve (pump curve) or ensure that the pump does not operate on the flat part of the curve. A combination of flow control and pressure control may be used in smaller systems. Temperature and level sensing controls may also be required. Whatever control system is utilized, operation of the pumps near their maximum efficiency points should be maintained.

An adequately sized pressure relief by-pass may be required to minimize pump cycling and prevent pump damage for pumps operating in the shut-off head condition. More information regarding pump control systems and automation is provided in *Section 9.6 – Automated/ Unattended Operation*.

7.3.10 Standby Power

Dedicated standby power is required to ensure that water may be treated and/or pumped to the distribution system during power outages to meet the average day demand. Alternatives to dedicated standby power may be considered with proper justification.

The need for standby power and the extent of equipment requiring operation by standby power should be individually assessed for each treatment plant (*Section 3.12 – Standby Power*).

The following approach should be adopted:

- In cases where no or inadequately sized floating storage is available for fire protection, it is recommended that full standby power be supplied. Typically, the size of the pumping stations in these instances is small and the standby power requirements low. As a result, it is normally the most economical approach to use standby diesel or natural gas generator sets; and

- Where adequate floating storage is available, the need to utilize standby power is less critical. A common approach is to provide sufficient standby power for the pump capacity equal to the average day demand rate. This should supply adequate quantities of water required in the event of a major power outage.

If standby power is required, it should be provided by means of an emergency standby generator set preferably; for small systems, a direct drive engine may be acceptable. The designer is referred to the AWWA *Emergency Power Source Planning for Water and Wastewater* publication

The fuel storage and fuel lines should be designed to protect the water supply from contamination (*Section 3.12.1 – Diesel Fuel Storage*) and in accordance with applicable Ontario regulations which govern the design and installation of fuel storage tanks.

Carbon monoxide detectors with audible alarms should be provided when generators are housed within pumping stations. Sound studies may be required to ensure that the operation of standby power equipment does not exceed ambient noise level limits. In some cases, noise attenuation measures may be required.

If the generator and motor are not sized to simultaneously run all equipment in the pumping station, non-essential equipment should be on separate power circuits which are not energized by the standby power unit.

7.3.11 Transformers

Suitable transformers should be supplied to meet all requirements in the pumping station. For larger pumping stations, it is recommended that either dual transformers and switchgear be supplied, or standby power be provided, such that continuous operation of at least half of the pumping station can be maintained.

7.3.12 Automatic & Remote Controlled Stations

All automatic stations should be provided with automatic alarms which will report when abnormal conditions or equipment faults occur. All remote controlled stations should be electrically operated and controlled and should have signaling apparatus of proven performance. Installation of electrical equipment is governed by the *Electrical Safety Code* (O. Reg. 164/99) under the *Electricity Act, 1998*.

7.3.13 Safety

Stations should be designed in such a manner as to ensure the safety of the operators and maintenance staff in accordance with the *Confined Spaces Regulation* (O.Reg. 632/05) made under the *Occupational Health and Safety Act* (OHSA). Typically, the following points should be considered:

- Any moving equipment should be covered with suitable guards to prevent accidental contact;
- Equipment that starts automatically should be suitably signed to ensure that operators are aware of this situation;
- Local lockouts on all equipment should be supplied so that maintenance personnel can ensure that they are completely out of service;
- Local emergency stops should be provided;
- Provision of fire/smoke detectors, fire extinguishers and sprinkler systems (where appropriate);
- All stairways and walkways should be properly designed with guardrails; and
- Minimizing confined spaces, where applicable.

More detailed information regarding safety should be obtained from the Ontario Ministry of Labour.

7.4 PUMPING CONSIDERATIONS

Pumps should be specified so that the full range of flows anticipated can be provided with pumps operating in the vicinity of their optimum efficiency points, with due regard to the hydraulic design of the discharge piping. This is often accomplished by selecting pumps which have wide band efficiencies and an appropriate operating curve.

The number of pumps should be consistent with the pattern of flow required and the method of flow control. It is recommended that at least three pumps be provided for operating flexibility; a minimum of two pumps is required, one as a redundant standby, with consideration of firm capacity of the pumping station (*Section 7.3.1 – Firm Capacity and Station Capacity*).

The station design should allow for future additional pump units and where possible, the piping should be large enough for an increase in pump size to be accommodated. Adequate space should be provided for the installation of these additional units and to allow safe servicing of all equipment.

The pumping station design should provide for flooded suctions at all times, otherwise, an adequate priming system should be provided with sufficient capacity to prime pumps within a short period, i.e., 1 to 2 minutes, as recommended by the pump manufacturer. To accomplish this, the designer should carefully review potential operating levels of wet wells or storage reservoirs and pump elevations.

Pumps should be selected which have maximum efficiencies at the average head condition, but which can meet the maximum flow and pressure conditions. Particular attention should be paid to pump suction piping design to ensure ***net positive suction head*** (NPSH) available exceeds pump specifications with respect to NPSH required to avoid ***cavitation***.

Adequate control should be provided which is capable of controlling pump operation over the entire range of flows expected. Where this is accomplished by control valves, the valves should be located on the pump discharge to maintain stable control and avoid cavitation. Other more energy efficient types of control, such as variable frequency drive systems, may be preferable provided that they allow for stable pump control. Alternatively, multiple pumps of different sizes or variable capacities may be provided to cover the expected range of flows and to ensure that they operate at their optimal efficiencies.

Large water systems (raw and treated) typically operate using pressure (level) control. For small water supply systems, where substantial seasonal variations in flow exist, it may be necessary to provide duplicate flow and pressure pump control systems – one suitable for very low flows (which normally occur in winter) and one suitable for the design maximum flows.

Pumping station headers should be adequately protected from transient pressure surges which may occur if pumps stop on power failure. Protection may be provided either by appropriate valves or hydraulic transient surge tanks. If pump discharge valves are provided, they should be slow acting type and properly controlled to avoid high transient pressures in the system on opening or closing. These valves should be interlocked with the pump operation to provide such protection (*Section 7.7.4 – Surge Arrestor Systems*).

7.4.1 Raw Water Pumping

For raw water pumping stations remote from the treatment plant, the designer should consider the use of slow opening pump discharge valves to minimize hydraulic transients.

The raw water wet well should be provided with an overflow of sufficient size or adequate surge volume to handle intake surges which occur on power failure (when all pumps stop). When designing to handle intake surge, a minimum Hazen-Williams coefficient of one hundred and fifty (C =150) should be applied. All electrical equipment and pump motors, except for immersible and submersible pumps, should be located above the surge water level.

Provisions should be made to prevent ***downsurge*** during hydraulic transients after power failure, which may cause problems if pump suctions become exposed and air becomes entrapped in the raw water pump suction piping.

7.4.2 Treated Water Pumping

The minimum number of pumps to be provided is two, in addition to any pumps required to provide fire flows. The minimum capacity should be equal to the maximum day demand and the actual capacity will be dictated by the distribution system and storage design and capacities. In each case, the firm capacity should be equal to or greater than the design capacity required. In case of vertical turbine pumps, the pump intake should be deeper than the lowest reservoir operating level and air release valves should be installed on the pump discharge.

Where backwash pumps draw from the same well as treated water pumps, the variations in well level and consequent variations in suction requirements should be considered when selecting the backwash pumps.

7.4.3 Booster Pumping Stations

The purpose of booster pumping stations is to maintain adequate pressures and flows in water distribution systems as a result of both changes in ground elevation and distance from the source of supply. This section addresses booster pumping stations of the two most common types: without associated storage for the service area (in-line), and with associated storage.

Booster pumping stations should be designed to service specific areas of a water distribution system based on defined limits. These areas are generally isolated from the remainder of the system by control valves.

Booster pumping stations may have incorporated with part of their operation, elevated or ground storage reservoirs which will serve to supply extreme demands, such as peak hour, fire flow and other emergency requirements.

Pumps taking suction from ground level ***storage tanks*** should be designed with adequate NPSH.

Booster pumps should be located or controlled so that automatic shutoff or low pressure controller maintains at least 140 kPa (20 psi) in the suction line under all operating conditions. A valve to control the pressure across the pump should be considered if suction and discharge pressures vary. Pumps taking suction from ground level storage facilities should be equipped with automatic shutoffs or low pressure controllers as recommended by the pump manufacturer, and the suction piping should be designed to allow for complete use of the full amount of water in the storage facility. Automatic or remote control devices should have a range between the start and cutoff pressure, or a cut off based on the low water level in the storage facility, which will prevent excessive cycling. A pump bypass should be available and alarms should be installed for such conditions.

Each booster pumping station should contain not less than two pumps with capacities such that firm station capacity can be satisfied with the largest pump out of service. In addition to the other requirements of this section, in-line booster pumps should be accessible for servicing and repairs.

Booster pumps should not be allowed for any service from the public water supply main, unless owned and operated by the water authority or if an air gap or backflow preventer upstream of the booster pump is provided.

Booster pumping stations, either alone or in conjunction with storage, should be capable of meeting the various demand requirements of the area being serviced. Analysis should be undertaken to determine each of the following conditions:

- Peak hourly flows when consumption is highest;
- Night flows when the consumption rate is at its lowest value and reservoirs remote from the source of supply are being filled by the booster station; and
- Fire flows which can occur at any time and which must be added to the maximum day rate.

Discharge pressure from the pumping station should be adequate to ensure that the pressure in the district to be served is within the range of 275 kPa (40 psi) and 700 kPa (100 psi), during peak and minimum demand periods. In the case of fire flows, it may be acceptable to allow the pressure in the system to drop to a level no lower than 140 kPa (20 psi).

If no or inadequate storage is available, the proposed booster pumping station should be designed in a manner that will allow it to supply all of the extreme flow conditions mentioned above.

Booster pumping stations serving pressure zones with adequate storage should be designed for the maximum day rate, as it may be cost prohibitive both in terms of pumping station capacity and watermain design to supply all extreme flow conditions directly from the booster pumping station (*Chapter 8 – Treated Water Storage*).

7.5 PUMPING COSIDERATIONS FOR SYSTEMS SERVING FEWER THAN 500 PEOPLE

7.5.1 Raw Water Pumping

Where low lift pumps are provided on a surface water source, a minimum of two units, each capable of the design flow, should be provided.

Low lift pumps should be submersible or vertical turbine and operation of the pumps should be regulated by high and low water level sensing devices located in the treated water storage reservoir. Control should be provided for the low lift raw water pumps to operate singly or together in automatic or manual modes.

Where filtration with backwash is provided, the low lift pumps should be controlled so that the discharge rate to the treatment units does not exceed the capacity of the treatment unit(s) remaining in operation during backwashing (as applicable). This can be accomplished by either providing sufficient additional storage at the treatment plant to permit complete shut-down of all treatment units during the backwash cycle or by installing a rate-of-flow controller on the low lift pump discharge which throttles/limits flow to the treatment unit to a capacity equal to that of the unit(s) remaining in service. In either case, the controls should be connected to the backwash pump cycle for automatic activation.

Refer to *Section 7.4.1 – Raw Water Pumping* for more information regarding raw water pumping.

7.5.2 Treated Water Pumping

Where high lift pumping is necessary, at least two pumps should be provided with each pump designed to deliver a minimum of the design maximum day flow at the desired head. In many instances, particularly for smaller systems with large flow variations, it may be desirable to provide a third domestic high lift pump with this pump sized to meet a lesser flow than the maximum day requirement of the system. In this case, this pump should be designed to lead during lower flow conditions. During normal periods of domestic demand, the smaller pump would provide an adequate supply of water, while the large pumps would only operate to accommodate higher demands or in the event of failure of the lead pump.

Where fire protection is to be provided via the communal water supply/distribution facility, a third high lift pump (fire pump) should be provided and the capacity of that pump should be at least equal to the minimum required fire flow.

In instances where the distribution system is not provided with an elevated ***storage tank*** and a ground storage reservoir located at the site of the treatment facility is the only storage, it may be necessary to provide pump(s) sized for the peak domestic demand, or maximum day demand plus the required level of fire flow. In this case, pump operations should be controlled by pressure switches.

Pressure regulating valves (PRVs) with pressure relief to the storage reservoir under low demand conditions should be provided for pressure regulation in the distribution system. In many instances, it may be advisable to provide pressure tanks for pump control in order to minimize the number of start-stop cycles and hence, wear and tear, on the pumping equipment.

Refer to *Section 7.4.2 – Treated Water Pumping* for more information regarding treated water pumping and *Chapter 8 – Treated Water Storage* and *Chapter 10 – Distribution System Piping and Appurtenances* for distribution system pressures requirements.

7.5.3 Pumphouses

For each water supply installation, a pumphouse should be constructed. The designer should refer to all applicable codes and regulations under the *Occupational Health and Safety Act* (OSHA), the *Building Code Act, 1992* and the *Fire Protection and Prevention Act, 1997* and local zoning by-laws. Refer to *Section 7.3 – General Design Considerations* for more information regarding the design of pumping stations.

The design of the pumping station discharge piping should minimize the number of high points. Any high points in the piping system should be equipped with a manually operated air release valve which has been threaded to permit the future installation of an automatic valve should this be found necessary.

7.5.4 Controls

The following controls may be provided between the storage reservoir and the high lift and low lift pumping equipment:

- A low level set-point to shut-off the high lift and fire pumping equipment when the water level in the reservoir drops to a pre-determined low level;

- A high level set-point to shut down the low lift pumps when the water level in the reservoir has reached a pre-determined high level; and
- Level sensors to operate the low lift pumps sequentially.

Pressure switches should be mounted on the discharge line from the high lift pumping station to operate the high lift pumping equipment sequentially. A pressure gauge should also be installed on the discharge of each high lift pump. Elapsed time meters should be provided for all high lift pumps. Output from the high lift pumping station to the distribution system should be metered with a recording type flow meter.

The start-stop operation of the fire pump should be arranged between the municipality/owner and the local fire officials. Indication of the operation status of the pump should be relayed to a central operating point where 24-hour surveillance is provided.

Refer to *Section 7.3.9 – Controls* for more information regarding pumping system controls.

7.5.4.1 Pressure Tanks

Pressure (hydropneumatic) tanks are used in small closed systems to maintain acceptable system pressures without the need for frequent stops and starts of the pumps. They should only be used in very small systems. When considering the use of pressure tanks, the designer should consider the implications of loss of pressure in the distribution system in the event of a power outage or pump failure (i.e., the need to issue a boil water advisory). Pressure tank storage should not be used for chlorine contact or fire protection purposes; fire flow requirements are typically provided by by-passing the pressure tanks. The designer should also consider the impacts of changes in pressure on the operation of the fire pump(s).

Pressure tanks should meet applicable American Society of Mechanical Engineers (ASME) code requirements. The maximum allowable working pressure should be marked on each tank.

Location
Pressure tanks should be located above grade and be completely housed. Enough space should be provided around the tank for inspection and maintenance.

Sizing
The capacity of the wells and pumps in a hydropneumatic system should be equal to the peak instantaneous demand. The active storage volume of the

hydropneumatic tanks should be sufficient to limit pump cycling to the manufacturer recommendations. The maximum cycling frequency should be determined for the largest pump when consumer demand is half of the capacity of the largest pump or combination of pumps operated by the same pressure switch.

Hydropneumatic tanks should only be designed for pump control to minimize the number of starts, and should never be used as means for providing disinfectant contact time or storage in any drinking-water system.

Piping
Pressure tanks should have means for isolation to permit operation of the system while a tank is being repaired or maintained.

Appurtenances
An automatic pressure release valve, mechanical means for adding air, including an air filter, and sight glass or other tank level indicator should be provided for maintenance of proper air/water volumes in the pressure tank at all times.

Control equipment consisting of a pressure gauge and pressure operated start-stop controls for the pumps should be provided for the pressure tank system. A shut-off valve should not be installed between the pump and the pressure operated start-stop controls.

The pressure relieving device should prevent the pressure from rising more than 10% above the maximum allowable working pressure. The discharge capacity of the pressure relieving device should be adequately sized. Pressure gauges should have a range of no less than 1.2 times the pressure at which the pressure relieving device is set to function.

An access hatch and drain should also be provided. Where practical, the access hatch should be 600 mm (24 in) in diameter.

7.6 PUMPS & MOTORS

7.6.1 Suction Lift & Priming

Suction lift should be avoided, if possible. If suction lift is necessary, it should be less than 4.5 m (15 ft) and provisions should be made for priming the pumps. To avoid pump cavitation, the NPSH required for a selected pump should be checked against the NPSH available for a given system to ensure that the latter is greater than the former.

Prime water must not be of lesser quality than that of the water being pumped. Means should be provided to prevent either ***backpressure*** or ***backsiphonage backflow***.

When an air-operated ejector is used, the screened intake should draw clean air from a point at least 3 m (10 ft) above the ground or other source of possible contamination. Vacuum priming may be used. Compressed air systems should be oil-free and filtered to prevent contamination of treated water.

7.6.2 System Head Curves

The design engineer should determine projected points of operating head and flow for at least the following conditions:

- Average day;
- Maximum day;
- Peak hour; and
- Minimum hour.

Pumps should be selected to ensure that they will operate satisfactorily over the necessary pumping ranges that can be expected at the pumping station (including stages of new development and associated water demand increases in the serviced area). The pumps should be capable of meeting at least the following criteria:

- The rated point which would generally correspond to the maximum day consumption rate;
- The rated point for efficiency evaluation, i.e., the point at which the pump would normally run and at which the pump should be selected for best efficiency;
- The possible operating range which would be the range over which the pump must operate from a minimum ***total dynamic head*** (TDH) to a maximum total dynamic head; and
- The minimum submergence level in the case of a vertical turbine unit, or the NPSH required in the case of horizontal centrifugal unit, should also be specified.

All four of these criteria should be evaluated when a pump is being selected. The unit should operate at a TDH considerably less than the ultimate rated point (shut-off head). As a result, the maximum efficiency point should be specified as to be the point at which the pump will normally run.

7.6.3 Constant Speed versus Variable Speed Pumping Units

In certain instances, for pumping stations located in a service area without the provision of adequate storage and where variations in pressure are critical, it may be desirable to use variable speed pumps with pressure control to meet the demand. The provision of variable frequency drives for high lift pumping is particularly advantageous in drinking water distribution systems with little or no system storage. Consideration may be given to operating variable and fixed speed units together to avoid forcing a pump into a shut-off position on its curve.

7.6.4 Water Seals

Water seals should not be supplied with water of a lesser quality than that of the water being pumped. Where pumps are sealed with treated water and are pumping water of lesser quality, either an approved reduced pressure principle backflow preventer or a break tank open to atmospheric pressure should be provided. Where a break tank is provided, an air gap of at least 150 mm (6 in) or two pipe diameters, which ever is greater, should be provided between the feeder line and the flood rim of the tank.

7.6.5 Motors & Starters

Each pump should be operated by a motor capable of operating the pump at any point on the head discharge curve. Pump motors over 15 hp should be certified by the supplier to have undergone standard commercial testing and be rated as “premium” energy efficient. Motors should be located at such a level in the pumping station that they can not be flooded. Alternatively, immersible/submersible motors can be used.

A suitable time delay between pump stop and the subsequent pump start should be provided to allow the shaft to come to a complete stop. Soft start motor starters should be considered when standby power is provided. Staggered pump start is recommended to reduce in-rush load on the generator.

7.7 APPURTENANCES

7.7.1 Valves/ Check Valves

Pumps should be adequately valved to permit satisfactory operation, maintenance and repair of the equipment. If foot valves are necessary, they should have a net valve area of at least 2.5 times the area of the suction pipe and they should be screened. Each pump should have a positive-acting check valve on the discharge side between the pump and the shut-off valve.

Valves, either of the gate or butterfly type, should be used for pump isolation and control valves (hydraulically activated globe or butterfly) for pump discharge operation. Typically, on larger installations [i.e., 250 mm (10 in) or greater], butterfly valves should be used. Gate or ball valves, especially for suction isolation, may be used for smaller sized piping.

Check valves should be mounted horizontally on pump discharges so that the valve will close slowly and automatically if station or pump flow stops.

7.7.2 Gauges & Meters

Each pump should have a standard pressure gauge on its discharge line and a ***compound gauge*** on its suction line. Pressure transducers or pressure indicating transmitters (PITs) for each pump should be provided in larger stations. Means should be provided for measuring the discharge flow of each pump. All stations should have flow rate indicating, totalizing and recording metering of the total water pumped. A magnetic flow meter, an insert Venturi meter or a mechanical meter may be used for this purpose. Flow meters are discussed in greater detail in *Section 3.18 – Flow Metering*. Mercury containing devices should not be used.

Sufficient space should be provided to ensure the accuracy of the metering device (for appropriate length of approach piping, consult the manufacturer recommendations). Valved by-passes should be provided for all meters to facilitate meter maintenance and calibration.

The designer should take into account the piping and orientation requirements for meter installation and application specifications. The designer should also note that air entrainment in process streams can have a negative impact on meter accuracy and functionality, and should be eliminated through air relief designs.

7.7.3 Suction & Discharge Piping

Suction and discharge piping should be designed and arranged in a way that meets the recommendations of the Hydraulic Institute. Piping should be designed so that the friction losses will be minimized. Piping should have watertight joints and the contents must not be subject to contamination or leakage. Piping should be protected against surge or water hammer and provided with suitable restraints where necessary. Piping should be designed such that each pump has an individual suction line or that the lines be manifolded such that they will ensure similar hydraulic and operating conditions.

Suction and discharge piping should be designed and arranged in such a way that it is easily accessible, with sufficient room to service all valves, meters and other appurtenances, and to permit their removal with minimum disturbance to the system. Piping should be arranged to allow ready disassembly from pump to shut off valves, and include a flexible type coupling to permit proper alignment of the piping and pump. Couplings should be adequately protected against thrust. Pump elbows should be supported to remove all bending moments, either steady or shock, from pump nozzles.

The following points should be considered in the design of the various components of the system:

- Suction piping should be designed in such a way to ensure that the NPSH requirements for the pumping unit involved are satisfied (positive suction design is recommended over negative suction);
- Suction piping should be at least one size larger than the pump nozzle, as straight and short as possible, and connected by an eccentric reducer to prevent air accumulation and cavitation;
- Suction piping velocities should be maintained according to Table 7-1:

Table 7-1: Suction Piping Velocities

PIPE DIAMETER	VELOCITY
Up to 250 mm (10 in)	1.0 m/s (3 ft/s) or less
From 300 to 800 mm (12 to 32 in)	1.5 m/s (5 ft/s) or less
Greater than 800 mm (32 in)	2.0 m/s (6.5 ft/s) or less

- An isolating valve should be installed on the suction side of the pump;
- Discharge piping velocities should range according to Table 7-2:

Table 7-2: Discharge Piping Velocities

PIPE DIAMETER	VELOCITY
Up to 250 mm (10 in)	1.0-1.5 m/s (3-5 ft/s)
From 300 to 800 mm (12 to 32 in)	1.2-2.0 m/s (4-6.5 ft/s)
Greater than 800 mm (32 in)	1.8-3.0 m/s (6-10 ft/s), max.3.0 m/s (10 ft/s)

- Piping should be designed to prevent the formation of air pockets; and
- All joints should be restrained in a manner that will not permit joints to pull apart.

7.7.4 Surge Arrestor Systems

A hydraulic transient analysis should be undertaken during the design of pumping stations to ensure that the transients resulting from events such as pumps starting, stopping, and full load rejection during power failure do not adversely affect either the customers on the water system or the piping in the station or the system. Methods of surge protection that can be used to protect stations include:

- Surge anticipator systems that dissipate over-pressure from the discharge lines;
- Slow closing and opening control valves on pump discharges;
- Hydropneumatic surge tanks on discharge headers; or,
- Variable speed pumping units.

Any discharge from such a system may be connected directly back to the water well or storage reservoir or may discharge to a drainage system provided that, in treated water situations, an adequate air gap is included to prevent backflow.

Surge relief valves or slow acting check valves should be provided to minimize hydraulic transients. Slow closing valves should operate during or immediately after power failure. The type and arrangement of check valves and discharge valves are dependent, in some part, on the potential hydraulic transients that might be experienced in the pumping station. In smaller pumping stations, mechanically operated check valves should be adequate. In large stations, consideration should be given to the method of starting and stopping the pumps. An electrically operated butterfly or hydraulically activated globe style valve, coupled with a check valve on the discharge, should be utilized for the starting and stopping sequence of a pump. Other types of valves may incorporate both the isolating valve and check valve characteristics into one common valve; however, suitable isolating valves should be available in the event that maintenance is required on combination type valves.

CHAPTER 8

TREATED WATER STORAGE

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CHAPTER 8

TREATED WATER STORAGE

This chapter provides guidance for the design of treated water storage in drinking-water supply systems.

8.1 GENERAL

Treated water storage facilities should be designed to allow maintenance of adequate flows and pressures in the distribution system during peak hour water demand, and to meet critical water demands during fire flow and emergency conditions. Storage volumes should be designed based on projected design populations.

One of the most important design objectives for water storage is to minimize the chance of contamination of the treated water. The designer should keep in mind that the purpose of water storage is to ensure continuity of supply and maintain system pressure. The materials and designs used for treated water storage facilities should provide structural stability and durability as well as preserve the quality of the stored water.

In addition to the information in these guidelines, the designer should refer to all applicable AWWA Standards which relate to the design of treated water storage facilities.

8.2 TYPES OF TREATED WATER STORAGE FACILITIES

The following are types of treated water storage facilities:

At the water treatment plant:

- Clearwells;
- Reservoirs;
- Pumping wet wells; and
- Pressure tanks.

In the distribution system:

- Elevated tanks;
- Standpipes; and
- Reservoirs.

The type(s) of water storage facility (facilities) selected will depend on many factors such as function, the size of service area, topography, costs, the balance between water treatment capacity and demand, and the amount of storage required at the water plant and in the distribution system.

8.3 PRESSURE CONSIDERATIONS

The minimum required water level and the location for a distribution system storage facility should provide acceptable service pressures throughout the distribution system as described below and as outlined in *Section 10.2 – Hydraulic Design*. System water demands in excess of maximum day requirements are normally met from storage. Storage facilities should be designed to maintain adequate pressure in the distribution system at the average day water demand in the event of a power failure or other emergency. This lessens the potential for groundwater intrusion and contamination of the system.

The maximum variation between high and low levels in elevated distribution system storage tanks should be such that the normal pressures in the distribution system do not go above 700 kPa (100 psi) nor below 275 kPa (40 psi) during normal demand periods. The normal operating pressure in water distribution systems should generally be in the range of 350 kPa to 480 kPa (50 to 70 psi) under maximum daily flow. However, pressures outside of this range may be dictated by distribution system size and/or topography. Pressures as low as 140 kPa (20 psi) may be acceptable when fire demands are experienced in conjunction with maximum day consumption rates. When static pressures exceed 700 kPa (100 psi), pressure reducing devices should be provided on mains or service connections in the distribution system.

8.4 SIZING OF STORAGE FACILITIES

Storage facilities should have sufficient capacity, as determined by engineering studies, to meet water demands that exceed the daily water supply capacity of the treatment plant and, where fire protection is provided, fire flow demands. Emergency planning including the provision of stand-by power would also influence the sizing of storage facilities. The water storage requirements (exclusive of storage needed for the operation of the water treatment plant) are described in *Section 8.4.2 – Sizing Treated Water Storage for Systems Providing Fire Protection* and *Section 8.4.3 – Sizing Treated Water Storage for Systems Not Providing Fire Protection* which follow.

Where appropriate for larger distribution systems, hydraulic and water quality models should be used for sizing new storage facilities and for selecting locations for re-chlorination facilities if needed.

8.4.1 Chemical Disinfection Contact & Water Treatment Plant Storage

Any volume required to provide chemical disinfection contact time is not available for storage and should not be included in storage calculations. Refer to *Section 5.9 – Disinfection* for more information on primary disinfection and contact time.

8.4.2 Sizing Treated Water Storage for Systems Providing Fire Protection

The following method for sizing water storage needs may not fulfill the fire protection requirements of the municipality insurance company or the Fire Underwriters Survey. For fire flow requirements, refer to the latest edition of the Fire Underwriters Survey document *Water Supply for Public Fire Protection*[12]. Historically, small municipalities in Ontario have used the following criteria.

Table 8-1: Fire Flow Requirements

EQUIVALENT POPULATION[1]	SUGGESTED FIRE FLOW (L/s)	DURATION (HOURS)
500 – 1 000	38 (10 ft/s)	2
1 000	64 (17 ft/s)	2
1 500	79 (21 ft/s)	2
2 000	95 (25 ft/s)	2
3 000	110 (29 ft/s)	2
4 000	125 (33 ft/s)	2
5 000	144 (38 ft/s)	2
6 000	159 (42 ft/s)	3
10 000	189 (50 ft/s)	3
13 000	220 (58 ft/s)	3
17 000	250 (66 ft/s)	4
27 000	318 (84 ft/s)	5
33 000	348 (92 ft/s)	5
40 000	378 (100 ft/s)	6
Note [1]: When determining the fire flow allowance for commercial or industrial areas, it is recommended that the area occupied by the commercial/industrial complex be considered at an equivalent population density to the surrounding residential lands.		

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[12] Fire Underwriters Survey is a national organization administered by (c/o) CGI Insurance Business Services, 150 Commerce Valley Drive, Lockbox 200, Markham ON L3T 7Z3, 905-882-6300, in Ontario.

Fire protection is a municipal responsibility and the municipality may elect to provide for higher fire flow requirements or entirely forgo fire protection by way of the drinking-water distribution system. The designer should, therefore, ensure that he/she is aware of all applicable requirements.

Total Treated Water Storage Requirement = A + B + C

Where: A = Fire Storage;
B = Equalization Storage (25% of maximum day demand); and
C = Emergency Storage (25% of A + B).

The maximum day demand referred to in the above equation should be calculated using existing flow data whenever possible, otherwise the factors in Table 8.2 may be used. Where existing data is available, the required storage should be calculated on the basis of the demand characteristics within the system.

Table 8-2: Maximum Day Peaking Factors

EQUIVALENT POPULATION[1]	MAXIMUM DAY FACTOR
500 – 1 000	2.75
1 001 – 2 000	2.50
2 001 – 3 000	2.25
3 001 – 10 000	2.00
10 001 – 25 000	1.90
25 001 – 50 000	1.80
50 001 – 75 000	1.75
75 001 – 150 000	1.65
Greater than 150 000	1.50

Note [1]: When determining the equivalent population for commercial or industrial areas, it is recommended that the area occupied by the commercial/industrial complex be considered at an equivalent population density to the surrounding residential lands.

Maximum Day Demand = Average Day Demand x Maximum Day Factor

The above equation is for the calculation of the storage needs for a system where the water supply system is capable of satisfying only the maximum day demand. For situations where the water supply system can supply more, the storage requirements can be reduced accordingly.

The physical configuration of the water containing portion of the storage facility should be such that the equalization volume (B) is located between the top water level (TWL) of the storage facility and that elevation necessary to produce a minimum pressure of 275 kPa (40 psi) in the majority of the system under peak hourly flow. The fire (A) and emergency (C) component volumes (i.e., A + C) should be located between that elevation necessary to produce 275 kPa (40 psi) under peak hourly flow conditions and that elevation necessary to produce a minimum 140 kPa (20 psi) under the maximum day plus fire flow condition.

Should a ***standpipe*** with a booster pumping station at the base be proposed, the equalization volume (B) would normally be located between the TWL and that elevation necessary to produce 275 kPa (40 psi) in the majority of the system under peak hourly flow. The fire (A) and emergency (C) components can be below this 275 kPa (40 psi) elevation provided the booster pump is designed/sized to increase system pressures to a minimum 140 kPa (20 psi) under the maximum day plus fire flow condition.

8.4.3 Sizing Treated Water Storage for Systems Not Providing Fire Protection

If the drinking-water system is not being used or will not be used for providing fire protection, the volume of storage should be 25% of the design year maximum day plus 40% of the design year average day.

8.4.4 Treatment Plant Storage

Significant storage may be required at water treatment plants for the proper operation of the plant. This storage is in addition to the storage requirements described in *Section 8.4.2 – Sizing Treated Water Storage for Systems Providing Fire Protection* and *Section 8.4.3 – Sizing Treated Water Storage for Systems Not Providing Fire Protection*. Treatment plant storage can be provided in treated water wet wells, clearwells and/or reservoirs.

The plant storage should be sized (together with distribution system storage capacity) to minimize on/off cycling of the treated water pumps. Plant storage should be sized such that distribution system demands and in-plant water use (e.g., filter washing, chemical systems, and domestic use) can be met while maintaining relatively constant flow through the plant rather than fluctuating filtration rates.

8.4.4.1 Filter Wash Water

Storage for filter wash water should be sized, in conjunction with backwash pump units and treated water storage, to provide adequate backwash water (*Section 5.6.2 – Rapid Rate Gravity Filters* and *Section 5.7.2 – Membrane Filtration*). Consideration should be given to the consequences of backwashing of several filters in rapid succession and/or worst case conditions when peak demand and backwash water requirements coincide.

8.4.5 Sizing Considerations for Systems Serving Fewer Than 500 People

If the system municipality/owner has decided that fire protection is not to be provided and the source is only capable of the maximum day, the minimum effective storage to be provided should be the average daily flow. Appropriate allowances for lawn watering and in-plant process requirements, as needed should be added to the minimum volume.

Where it has been decided that fire protection is to be provided via the communal water supply and distribution system, the minimum volume of the storage facility should be increased by an amount equal to the minimum fire flow for two hours. The allowance for lawn watering is not needed where fire protection is provided via the communal water supply and distribution system.

In sizing storage facilities for small systems, the designer should also consider the importance of maintaining water quality, preventing freezing during the winter and excessive warming of the water during the summer.

8.5 LOCATION OF STORAGE/ SITE SELECTION CONSIDERATIONS

The following factors should be considered in choosing a location for distribution system storage:

- The relationship of distribution system hydraulics (including topography) and water demands in various parts of the system;
- Pumping and transmission costs;
- Safety considerations;
- Aesthetic considerations and public property owner acceptance;
- Future expansion; and
- Site access.

A location in an area of the highest water demand and/or low pressure should be preferred. Storage facilities should ideally be located on the highest point of ground in the area. For large distribution systems, the placement of one storage tank at central location should be evaluated against smaller units with equivalent total volume in other parts of the system. The designer should be aware that flow reversals may create sediment uptake and dispersal. This may be a more significant issue where the storage tank is located at an extremity of the distribution system.

In addition, the following factors should be considered in choosing a location for ground-level or buried reservoirs:

- Structural costs based on soil conditions and location of the groundwater table (the bottom of the reservoir should ideally be above the groundwater table, or alternatively site drainage should be provided);

- Where groundwater levels have the potential to cause floating, structural measures to prevent floating should be incorporated in the design;

- Excavation costs based on cut and fill considerations; and

- Any opening in the reservoir should not be less than 600 mm (24 in) above the original ground level or the level of the 100 year flood (or the highest flood of record).

Sewers, drains, septic tanks and tile fields, standing water and similar potential sources of contamination should be kept at least 15 m (50 ft) away from the reservoir. Where this separation cannot be obtained, sewers constructed of watermain quality pipe, pressure tested in place at a pressure of 350 kPa (50 psi) without leakage may be used at distances greater than 6 m (20 ft) in accordance with the Ontario Ministry of Transportation *Ontario Provincial Standard Specification 701* (OPSS 701) of the *Ontario Provincial Standards for Roads and Public Works* (OPS).

8.6 SECURITY & PROTECTION

All existing and future water storage structures should be completely covered and watertight to prevent contamination. Any openings should have covers to prevent the entry of birds, animals, insects, runoff and excessive dust. The installation of additional equipment such as antennae should not affect internal coatings or compromise water quality.

Where pipelines are located underneath or close to a reservoir, the use of rigid pipe or pipe with adequate joint flexibility is recommended to minimize potential damage due to differential settling or movement of the reservoir.

Fencing or other security measures, as well as locks on valve and vent housings and access hatches, should be provided at the storage site along with other precautions (e.g., alarms) to guard against illegal entry, vandalism and sabotage. The designer should consult the AWWA *Security Guidance for Water Utilities* document.

8.7 CONTROLS & IMPLEMENTATION

Adequate instrumentation to control water levels in storage facilities should be provided. Level indicating devices should provide readings at a central location and overflow and low-level alarms, activated by separate and independent devices, should sound at location(s) which will be monitored 24 hours a day. Local level indicators should be provided by a pressure gauge on the tank piping, a level indicating transmitter or other means. For ***elevated tanks***, level control instrumentation should be sufficiently precise to prevent wasting storage or tank overflows.

High lift and/or booster pumps should be designed to operate to maintain storage facility water levels within a range to maintain adequate distribution system pressure. Altitude valves or equivalent controls should be installed on elevated storage when more than one tank is required within a single supply pressure zone or where the storage facility would overflow at allowable high distribution system pressure.

8.8 DESIGN CONSIDERATIONS

8.8.1 Construction Materials

All chemicals and water contacting materials used in the construction and operation of drinking-water systems should meet all applicable quality standards as described in *Section 3.26 – Chemicals and Other Water Contacting Materials*.

The use of concrete form release agents that contain diesel oil or other potential water tainting components should be avoided.

Designers should be aware that concrete spalling has seriously damaged water saturated concrete during the freeze/thaw cycles that are typical in Ontario.

8.8.2 Maintaining Water Quality

Stagnation and excessive retention time in the distribution system may result in a deterioration of water quality. The deterioration may be indicated by loss of disinfectant residual, formation of disinfection by-products and bacterial re-growth. Therefore, storage facilities should be designed to prevent stagnation and minimize detention times. This may be assisted by providing separate inlet and outlet piping, a two-cell design, baffle walls, diffusers and/or by strategic location of the inlet and outlet piping. Where there is more than one cell, the inlet should be to one cell and the outlet from another. It should be possible to operate with one cell out of service. In standpipes where only the upper portion of the stored water provides useful system pressure, the water should be circulated through the storage facility to maintain quality and minimize ice formation. For smaller systems, circulation may be required to prevent high water temperatures.

If it is not possible to have sufficient turnover of water in a storage facility to maintain water quality, a pumped recirculation system should be provided and a booster disinfection system may be required.

Water quality deterioration in storage may be particularly rapid where sequestering agents are used with hard water or where natural organics react rapidly with a free chlorine residual. In such cases, the use of monochloramine as the secondary disinfectant should be considered by the designer. The designer may also consider the provision of re-chlorination systems at storage facilities in order to maintain acceptable chlorine residuals. Refer to *Section 5.9 - Disinfection* for more information on secondary disinfection.

The designer should refer to a publication such as the AwwaRF report *Maintaining Water Quality in Finished Water Storage Facilities* (Project #254).

8.8.2.1 Equipment Containing Mercury

Except for UV lamps, equipment containing mercury should not be used within a drinking-water system. UV systems should be designed to protect the water from mercury contamination. Refer to *Section 5.9 - Disinfection* for more information on UV systems.

8.8.3 Isolation & Drainage

The system should be designed to ensure that pressure can be maintained even when the storage facilities are drained for cleaning and maintenance. Consideration should be given to the installation of air release/vacuum relief valves on the distribution side of the isolation valve(s).

The storage facility drain should discharge to the ground surface with no direct connection to a sewer or storm drain. If a connection to a sewer or storm drain is unavoidable, an atmospheric gap of twice the drain diameter should be provided.

Floors should be sloped towards the sump to facilitate cleaning.

All buried reservoirs should be designed with two or more cells which can be operated independently, and a separate wet well when applicable. Through valving it should be possible to isolate one of the two cells without affecting the operation of the other cell. Two cells can often be provided as a result of construction phasing requirements.

8.8.4 Vents

Treated water storage facilities should be vented. The overflow pipe should not be considered a vent. Vents should:

- Allow air into the tank at a rate greater than the rate at which water is withdrawn in order to avoid the development of vacuum/pressure within the tank;
- Prevent the entrance of surface water and rainwater;
- Exclude birds and animals;
- Exclude insects and dust, as much as this function can be made compatible with effective venting;
- Be located away from areas which will be subject to severe snow drifting; and
- Eliminate entry of solid/liquid agents as a result of vandalism or sabotage.

On ground-level facilities, the vent should terminate in an inverted "U". The opening should be 600 to 900 mm (24 to 36 in) above the roof or groundcover and covered with twenty-four mesh non-corrodible screen. Where a valve house or pump house is provided, the vents should be located within the structure.

On elevated tanks and standpipes, vents should open downward and be fitted with either twenty-four mesh [0.70 mm (0.03 in) openings] non-corrodible screen or with finer mesh non-corrodible screen in combination with an automatically resetting pressure-vacuum relief mechanism.

8.8.5 Overflow

All water storage facilities should be provided with an overflow which discharges 300 to 600 mm (12 to 24 in) above the ground surface over a drainage outlet structure or a splash pad which drains away from the storage facility. No overflow should be connected directly to a sewer or storm drain. If such a connection is unavoidable, an air gap equal to twice the overflow pipe diameter should be provided. All overflow pipes should be located such that any discharge is visible. Alarms should be installed to alert the operator of an overflow event.

When an internal overflow pipe is used on elevated tanks, it should be located in the access tube. On other types of storage facilities, the overflow pipe should be located on the outside of the structure.

Overflows should open downward and be fitted with twenty-four mesh [0.70 mm (0.03 in) openings] non-corrodible screen. The screen should be installed within the overflow pipe at a location least susceptible to damage by vandalism. If a flapper valve is used, the screen should be installed upstream of the valve. The screen should be located such that it can easily be replaced following an overflow event.

The overflow pipe should be of sufficient diameter to permit discharge of water in excess of the maximum potential filling rate.

8.8.6 Roof & Sidewall

Watertight roofs should be provided. There should be no opening in the roof or sidewall except properly constructed piping for inflow and outflow, vents, access hatches, overflows, risers, drains, pump and valve mountings and control ports. Particular attention should be given to the sealing of roof structures which are not integral to the tank body.

Any pipes running through the roof or sidewall of a metal storage facility should be welded or properly gasketed. In concrete structures, these pipes should be connected to standard wall castings which were poured in place during the forming of the concrete or pipes should be sealed using rubber link type seals. Wall castings should have water stop flanges or seepage rings embedded in the concrete.

Openings in the roof or top of a storage facility designed to accommodate control apparatus or pump columns should be curbed and sleeved with proper additional shielding to prevent contamination from surface water or floor drainage.

Where possible, valves and controls should be located outside the storage facility so that the valve stems and similar projections will not pass through the roof or top of the reservoir. As an alternative approach, such valves and controls may pass through the roof or reservoir top provided they are located within a valve or pump house structure on the roof and are curbed.

The roof of the storage facility should be well drained. Downspout pipes should not enter or pass through the reservoir. If the design includes parapets or similar construction which would tend to hold water and snow on the roof, drainage should be provided.

Particular attention should be paid to expansion joint design for large structures to ensure long lasting protection against infiltration from deteriorating joints during expansion and contraction movement.

For elevated tanks and standpipes, the use of heat trace cables on the roof may be necessary to prevent the build up of ice.

8.8.7 Grading

The grading around ground-level facilities should direct water away from the tank and prevent standing surface water within 15 m (50 ft). Side slopes should have a grade no steeper than 3:1 to facilitate landscape maintenance.

8.8.8 Safety

Safety of the employees must be considered in the design of the storage facility. As a minimum, the design should conform to applicable laws and regulations of the Province. See Section 7.3.13 – Safety. Confined space entry requirements should be considered.

Ladders, ladder guards, railings, handholds and entrance hatches should be provided where applicable. The design should incorporate easily accessible fall arrest systems for use by employees or emergency response workers for access to the exterior and interior of the structure.

8.8.9 Internal Catwalk

Every catwalk over treated water in a storage facility should be located above the high water level and have a solid floor with sealed edges raised to 100 mm (4 in) designed to prevent contamination.

8.8.10 Silt Stop

The discharge pipes from water storage facilities should be located in a manner that will prevent the flow of sediment into the distribution system. Silt stops should be provided.

8.8.11 Disinfection & Backflow Prevention

Treated water storage facilities should be disinfected in accordance with AWWA *Standard C652: Disinfection of Water-Storage Facilities* before being placed into operation after construction, maintenance or repairs as required by the *Procedure for Disinfection of Drinking Water in Ontario* (Disinfection Procedure).

The designer should consider the need for dechlorination of highly chlorinated water that will be discharged to the environment in the course of draining for maintenance, overflows or other purposes.

Consideration should be given to backflow prevention during the initial fill of a storage facility or following maintenance.

8.8.12 Provisions for Sampling

Smooth-nosed sampling tap(s) should be provided for collection of water samples for both bacteriological and chemical analyses. The sample tap(s) should be easily accessible and located on the tank side of isolation valves. Sample suction locations should be placed in such a way as to be representative of the desired sample location.

Sample lines should be stainless steel from the sampling point to the sampling tap.

8.8.13 Freezing

Treated water storage facilities, especially the riser pipes, overflows and vents should be designed to prevent freezing which will interfere with proper functioning and cause potential damage to the structure.

Alternatives to be considered to avoid freezing include insulation, variable level operation, internal heating via heat tracing cables, hot water recirculation, separate inlet (high) and outlet (low) piping or a combination of these methods. If a water circulation system is used, the circulation pipe should be located separately from the riser pipe.

Refer to *Chapter 12 – Challenging Conditions* for further information on avoiding freezing.

8.8.14 Access

Treated water storage facilities should be designed with convenient and safe access [i.e., a minimum 900 mm x 1060 mm (36 in x 42 in) opening is recommended] to the interior for sample collection, cleaning and maintenance. Where space permits, at least two (2) access hatches should be provided above the waterline into each water compartment. The number and location of access hatches should comply with the requirements of the *Occupational Health and Safety Act* (OHSA).

For elevated storage tanks, at least one of the access hatches should be framed at least 100 mm (4 in) above the surface of the roof at the opening. It should be fitted with a solid watertight cover which overlaps the framed opening and extends down around the frame at least 50 mm (2 in), be hinged on one side and have a locking device. All other access ways should be bolted and gasketed.

For ground-level facilities, each access hatch should be elevated at least 450 mm (18 in) above the top of the tank or groundcover and should be fitted with a solid, watertight cover which overlaps a framed opening and extends down around the frame at least 50 mm (2 in). The frame should be at least 100 mm (4 in) high. Alternatively, the cover should have an integral perimeter trough and drain. Each cover should be hinged on one side using non-removable hinges and should have a locking device. All accesses should have a high degree of security to prevent unauthorized access.

8.8.15 Corrosion Protection

Proper protection should be given to metal surfaces by paints or other protective coatings, by cathodic protective devices, or by both.

Coatings formulated without the use of volatile solvents (termed 100% solids) and NSF/ANSI Standard 61: *Drinking Water System Components - Health Effects* certified should be used on the inside surface of steel structures to avoid the trapping of solvents and the resulting water tainting.

Cathodic protection of steel water structures should be provided and conform to the provisions of AWWA *Standard D104: Automatically Controlled, Impressed-Current Cathodic Protection for the Interior of Steel Water Tanks*. Considerations should be given to potential ice damage to cathodic protection equipment.

8.9 TREATMENT PLANT STORAGE

8.9.1 Clearwells & Reservoirs

A minimum of two compartments should be provided in clearwells and reservoirs. The plant should be able to operate for short periods with the clearwell or reservoir out of service. The design should also include adequate measures for circulation, an overflow and vents (*Section 8.8 – Design Considerations*).

When part of a clearwell or reservoir is to be used for disinfectant contact time (in addition to the storage volume), special attention should be given to baffling. Refer to *Section 5.9 - Disinfection* for more information about disinfectant contact time.

8.9.2 Adjacent Storage

Except where it is an inherent and necessary feature of the treatment process unit, drinking water should not be stored or conveyed in a compartment adjacent to non-drinking water when the two compartments are separated by a single wall. Pipes carrying non-drinking water should not be installed through storage facilities containing drinking water.

8.9.3 Other Treatment Plant Storage Facilities

Other treatment plant storage facilities such as chlorine contact tanks and wet wells for treated water should be designed as treated water storage facilities.

CHAPTER 9

INSTRUMENTATION & CONTROL

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CHAPTER 9

INSTRUMENTATION & CONTROL

Instrumentation and controls should be provided to allow safe and efficient operation of all parts of the drinking water treatment plant and distribution system. The requirements for instrumentation and control will be highly dependent on the size and complexity of the plant and the extent of remote operability. The municipality/owner and the designer together should determine the degree of automation to be provided to support operation of the drinking-water system.

9.1 GENERAL

The objectives of instrumentation and control are to support the continuous production of high quality drinking water in an efficient manner in terms of staff and resources used, and to satisfy the regulatory requirements for monitoring and recording operational data in accord with a control philosophy document prepared by the designer.

For information regarding monitoring and control systems for poisonous gases such as chlorine or ozone, the designer should refer to the supplier or manufacturer recommendations for health and safety.

9.2 PROCESS NARRATIVE & BASIS OF CONTROL

The designer should prepare a report which provides a process narrative for the drinking-water system that briefly describes each component of the drinking-water system, including the raw water quality, intake structure, treatment and pumping equipment, distribution system components, instrumentation, and monitoring and sampling equipment as applicable. In addition, the report should also identify and explain the basis of control for the system.

Process and instrumentation diagrams (P&ID) should be developed for all drinking-water system facilities and should include all major and minor processes along with all ancillary process equipment.

Control systems should be designed with a user-friendly human-machine interface (HMI) system to facilitate plant operation and on-line monitoring. Equipment status, flow rates, water levels, pressures and chemical feed rates should all be displayed via an HMI. All automated systems should be designed with a manual override or another form of redundancy to allow safe operation in the event of a hardware or communication failure.

9.3 CONTROL SYSTEMS

The type of control provided for the operation of a drinking-water system can vary from simple manual control without any automatic function (either local or remote), through semi-automatic control which combines manual control with automatic control for a single piece of equipment, to a fully automatic control system which turns equipment on and off or adjusts operating status in response to signals from instruments and sensors.

In selecting a control system, the designer and the municipality/owner should consider the following factors.

Manual Control Systems:

- Are simpler to maintain and repair than automatic systems and are lower in initial cost, but require the on-site presence of an operator when producing drinking water; and
- The initial low costs may be outweighed by high labour and operating costs including, chemical and energy costs incurred by poorer process control.

Automatic Control Systems:

- Provide a more consistent product with lower labour costs;
- Require skilled maintenance;
- Should provide a level of reliability appropriate for the control function; and
- Should be designed to have the capability to manage any set of conditions which may occur.

The designer should select a control system based on the risks to public health, the complexity of the processes to be controlled, and should take into consideration the capability and limitations of the knowledge and skill of regular operating staff.

Control systems should be fully alarmed with process deficiencies immediately apparent to the operators. All automatic controls should be provided with manual override and/or back-up systems, depending on the nature of the process being controlled, as well as status and alarm archiving for review as required.

Automatic remote control systems should include means for detecting communication failure (e.g., by using "heartbeat" communication integrity confirmation). In the event of communication failure, the designer should ensure safe mode operation or safe shut down of the remote part of the system. The designer should make provision for the system to resume operation automatically when communication is restored or remain shut down until attended by an operator. Redundant communication pathways should be considered for critical remote controls, with either automatic or manual switching. Primary instruments (sensors or analyzers) which form part of an automatic control loop should have appropriate redundant means of avoiding unsafe operation in case of instrument failure. The design should minimize pressure transients in the water distribution system following shut downs.

9.4 MONITORING

The design must satisfy the minimum requirements for drinking-water systems monitoring as set out in the *Safe Drinking Water Act, 2002* (SDWA), regulations under it and the *Procedure for Disinfection of Drinking Water in Ontario* (Disinfection Procedure).

Table 9-1 shows frequently used surface water treatment process related monitoring systems that the designer could consider (but not be limited by) in designing instrumentation and control systems. Selection of the level of instrumentation and control should be made in conjunction with the municipality/owner, considering factors such as:

- Level of maintenance and calibration required;
- Desired versus required level of automation;
- Data retrieval and storage requirements; and
- Capital costs.

The use of single analyzers or primary devices on a time-share basis for monitoring multiple points is discouraged. However, if adopted, the rate of sample flow to the instrument should be sufficient to give a true indication of the sample value within the time allotted to that sample. Sample line length and transport time to the analyzer should be taken into account for proper loop control. The designer should ensure any specific instrument installation requirements are met (e.g., upstream/downstream minimum pipe lengths for flow meters, turbidity analyzer de-bubblers[13], and minimum/maximum instrument flow rates).

The designer should ensure that samples taken are fully representative of the true conditions, (e.g., proper mixing and reaction of chemicals has occurred).

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[13] Excessive sizing of de-bubblers leads to averaging of turbidity data which obscures true filter performance.

Where analysers are part of an automatic control loop, the system lag time should be minimized to avoid hunting or other instabilities.

Table 9-1: Frequently Used Surface Water Treatment Process Related Monitoring System

PROCESS	MONITORING SYSTEMS
Raw Water	• Raw water turbidity, pH, temperature, conductivity, ammonia • Instantaneous flow rate and totalized volume per day • Mussel control related sub-systems • Particle counters
Coagulation/Flocculation	• pH • Coagulant and coagulant/filtration aid feed rates • Streaming current • Mixers speed/power
Sedimentation	• Effluent turbidity • Sludge level • Blow down valve status and flow rate
Solids Contact Clarifiers	• Effluent turbidity • Sludge level • Blow down valve status and flow rate
Proprietary Clarifiers	• Instrumentation for proprietary clarifiers including ballasted flocculation and dissolved air floatation should be provided in accordance with manufacturer recommendations • Effluent turbidity
Lime Softening	• pH following lime addition and recarbonation
Filtration (granular media)	• Influent water level • Influent turbidity, filter-to-waste turbidity • Mandatory individual filter effluent turbidity • Filtration rate • Effluent control valve position • Water level in filters • Head loss • Filter run time • Filter effluent particle counts • Filter status (e.g., on-line, backwash required, in backwash, ready, off-line)
Backwash	• Backwash flow rate and totalized volume • Air scour/ surface wash status • When automated, control sequence status
Filtration (membrane)	• Instrumentation should be provided in accordance with manufacturer recommendations • Turbidity/particle count/integrity test on each individual filter train effluent

Table 9-1: Frequently Used Surface Water Treatment Process Related Monitoring System

PROCESS	MONITORING SYSTEMS
	• Filter train flow rate • Pressure differential • Filter train status (e.g., on-line, backpulse, clean, off-line)
Clearwell	• Water level • Minimum water level where it is required for confirmation of primary disinfection
Treated water	• Turbidity, pH, chlorine residual, fluoride residual (if system fluoridates), colour, temperature, ammonia • Instantaneous flow rate and totalized volume per day • High lift discharge pressure • Minimum water level where it is required for confirmation of primary disinfection
Chemical Systems	• See Chapter 6 – Chemical Application
UV Systems	• Instrumentation needed to monitor and record pass through dose. See Chapter 5 - Treatment
Pumps and Motors	• Running time • Bearing temperature • Power draw • Speed, if variable speed • See also Chapter 7 – Pumping Facilities
Rotating elements (e.g., mixers, flocculators, solids contact clarifier recirculators and rakes)	• Torque or torque alarm
Residuals Treatment	• As required to ensure proper operation of the process (e.g., flow, turbidity, TSS, pH, temperature, sludge density)

9.4.1 Alarms & Status Indication

The designer should ensure that alarms are included where operator response is necessary to maintain the safety of the water supply and for all control system interlocks that can shut down equipment or systems.

All alarms should be latched (remain active) until an operator has acknowledged them. The automated alarm system should provide clear information on the condition and have a feature that records the identity of the operator and time of acknowledgement/cancelling, allowing proper log book entries that are cross referenced to automated records. If an alarm is indicated on a computer screen, an appropriate colour code or symbol should be used to indicate, for each alarm, whether it has been acknowledged. Alarm prioritization should be considered so that critical alarms on process systems are immediately addressed. The system should archive alarm data for easy retrieval as required.

Valve and equipment status should use a consistent method of symbols and colours, whether the status is indicated through lamps or on a colour computer screen. The colour-coding scheme should be consistent with any existing equipment displays elsewhere in the plant.

In plants that are left unattended for periods of time, an automatic telephone dialer, cellular or other radio communication or pager system for annunciation of alarms should be provided.

9.5 RELIABILITY & SECURITY

Hardware and software should be selected based on reliability, compatibility and vendor support. Equipment should be robust enough for continuous operation in the plant environment. Hardware and software necessary to facilitate back-up of both the system and the collected data should be provided locally.

A system and data recovery procedure should be included in the project documentation which should also be remotely accessible.

The designer should consider methods of improving reliability through transient protection wherever possible (e.g., mains, filters and transient surge protectors). Radio modem and other data transmission equipment should use methods to ensure the integrity of the data transmitted against corruption/interference. Encryption of signals for data/control security may be considered. When long or very long instrument or equipment wiring is present, induced current protection should be installed. Network configurations should be designed with security in mind. Protection of fibre optic or local area network (LAN) cabling in conduits should be considered to protect from physical damage. Harmonics and other electrical related disturbances to signal integrity should be taken into consideration.

Power supply design should include backup power by using true online uninterruptible power supply (UPS) or equivalent power systems. Buffered direct current (DC) power supply should be selected. Critical instrumentation should be connected when possible to the same back up power as the control system to allow monitoring during power outages. Consideration of the impacts of power failures on critical instrumentation and control should be taken into account, especially with respect to the reset conditions of the devices.

The computer human machine interfaces (HMI) should be user-friendly to facilitate operation and on-line monitoring. Where outside access is provided for remote control of the operator interface or other control components, adequate security should be provided.

Reasonable computer security measures should be provided if computer or other control systems are part of a larger system or a wide area control system or network. A vulnerability assessment document should be provided to the municipality/owner. This document should identify all potential access points, the associated risks with each and ways to mitigate those risks. Computer and programmable equipment, including calibration instruments, should use password protection and record accessing identity. Drives (including USB ports) should be locked down under regular operation whenever possible. The HMI should not allow switching to other programs under operator accounts (not even using combination keys). In larger systems which are part of an IT infrastructure, a narrower security policy should be defined that prevents disruption within the process control network (PCN).

9.5.1 Accessibility for Calibration & Maintenance

The design should arrange for easy access to all instrumentation and control systems for calibration and maintenance. Smart instrumentation is an emerging field that may be considered for improving servicing, calibration, failure detection and predictive maintenance of critical devices.

9.6 AUTOMATED/ UNATTENDED OPERATION

The designer should consider the consequences and operational response to treatment challenges, equipment failure and loss of communications or power.

Automated monitoring of all critical functions with major and minor alarm features should be provided; dual or secondary alarms may be necessary for critical functions. The designer should consider and document if automatic shutdown and manual restart is necessary or desirable to ensure the safety of the water supply. The control system should have response adjustment capability on all minor alarms. Built-in control system challenge test capability should be provided to verify operational status of major and minor alarms throughout the extreme conditions that can reasonably be expected during facility operation.

Automated shut-downs of high lift pumps due to low concentrations of chlorine residual or other water quality alarms or operational procedure, when sustained, may result in health risks similar to those experienced during power failure (*Section 3.12 – Standby Power*).

Provisions should be made to ensure security of the treatment facilities, pumping stations and storage facilities at all times. Appropriate intrusion alarms should be provided and sound at location(s) which will be monitored 24 hours per day. Video surveillance systems should be considered whenever possible.

9.7 COMMISSIONING/ ACCEPTANCE TESTING

A demonstration period to verify the reliability of procedures, equipment and surveillance system should be planned. Challenge testing of each critical component of the overall system should be included as part of the demonstration period. A report following the demonstration period should identify and address any problems and alarms that occurred during the demonstration period as well as a description of tests performed and their evaluation.

The designer should make provision for testing the control system during a period of operation or an appropriate period that reflects the range of operating conditions anticipated, which includes periods of seasonal changes or variations, to compare the actual control sequences with those described in the control narratives. Control narratives should be updated after the testing and as needed to reflect the "as is" status.

9.8 DOCUMENTATION

The designer should provide a reasonable level of documentation for the control installation. As a minimum, the following items should be included:

- Control philosophy document and control manual, including redundancy philosophy for critical systems;
- Process narrative;
- Instrument specifications;
- Loop diagrams;
- P&ID drawings for the entire control system, including remotely controlled equipment;
- Electrical and Interlock diagrams;
- Equipment manuals;
- Comprehensive maintenance and calibration procedures for instruments and control systems; and

- A disaster recovery procedure (system and data recovery procedures).

Refer to *Chapter 2 - Project Design Documentation* for more detailed information.

CHAPTER 10

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CHAPTER 10

DISTRIBUTION SYSTEMS

These guidelines outline parameters to assist in the design of water distribution systems. Other approval authorities such as the local or regional municipality may have standards that are more stringent than these guidelines. The designer should, therefore, ensure that he/she is aware of the requirements of all other approving authorities before commencing design.

Although some aspects of the guidelines relate only to municipal services, these guidelines are meant to apply to other systems such as mobile home parks and condominium developments.

10.1 GENERAL

10.1.1 High Quality Distribution Systems

The report of the Walkerton Commission includes the following definition: "A high-quality distribution system is reliable, providing a continuous supply of potable water at adequate pressure. Reservoirs within the system balance pressure and cope with peak demands, fire protection, and other emergencies without causing undue water retention, while looped watermains prevent stagnation and minimize customer inconvenience during repairs. Since water quality declines with the length of time the water remains in the system, and the rate of decline depends partly on the attributes of the distribution system, a high-quality system has as few dead ends as possible and maintains adequate flow and turnover"[14]. The designer should strive to achieve these objectives.

10.1.2 Fire Protection

Whether or not fire protection is provided via the communal drinking-water system is the decision of the municipality/owner of the system and can be subject to a cost/risk-benefit analysis, especially for smaller systems. However, once the decision has been made to provide fire protection via the communal drinking-water system, the designer should consult the *Fire Code* (O. Reg. 388/97) made under the *Fire Protection and Prevention Act, 1997* and the latest edition of Fire Underwriters Survey document *Water Supply for Public Fire Protection*[15] and the municipality/owner decision respecting fire protection. The designer should refer to AWWA *Manual of Water Supply Practices M31 – Distribution System Requirements for Fire Protection* and *Section 8.4 – Sizing of Storage Facilities* for more information regarding required fire flows.

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[14] Part Two Report of the Walkerton Commission of Inquiry, 2002, p. 234.

[15] Fire Underwriters Survey is a national organization administered by (c/o) CGI Insurance Business Services, 150 Commerce Valley Drive, Lockbox 200, Markham ON L3T 7Z3, 905-882-6300, in Ontario.

The designer should also consider local fire flow rates when sizing the pipes. In some cases, it may be necessary to evaluate the provision of separate pipes for fire and potable supplies to maintain water quality.

10.1.3 Maintaining Water Quality

Water distribution systems should be designed to provide a balance between hydraulic water supply needs and water quality. Water quality issues are categorized as microbiological (e.g., bacteria, regrowth, nitrification), chemical/physical (e.g., disinfection by-products, lead and copper, maintenance of secondary disinfectant residual) or aesthetic (e.g., colour, taste, odour). Many water quality issues have a direct potential public health impact.

Water quality deteriorates through interactions between the pipe wall and the water, and reactions within the bulk water itself. Depending on the retention time in the system, water flow, treated water quality, pipe materials and condition and deposited materials (i.e., sand, iron, manganese), the water quality will change to a greater or lesser extent[16]. Therefore, water age, a function of system design, water demand and system operation, is a major factor in water quality deterioration within the distribution system. Systems should be designed to maximize turnover and to minimize retention times and water age. Careful consideration should be given to distribution main sizing, providing for multidirectional flow, adequate valving for distribution system control and provisions for flushing and occasional "swabbing". In addition, positive pressure must be maintained at all times to prevent intrusion of contaminants. The designer should consult references such as the AwwaRF report *Guidance Manual for Maintaining Water Quality in the Distribution System* (Project #357), 2000 and the USEPA document *Distribution System White Papers*.

10.1.4 Interconnections

If interconnections between distribution systems or different water supply sources are planned, consideration should be given to differences in water quality and characteristics, and the implications of mixing different waters, such as water from a distribution system where chloramination is used with water from a system where free chlorination is used for secondary disinfection.

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[16] U.S. Environmental Protection Agency, Distribution System White Papers, *Decay in Water Quality Over Time (Effects of Water Age on Distribution System Water Quality).*

10.1.5 Multiple Pressure Zone Systems

The designer should have regard to the effects of water age and potential water quality deterioration when designing interconnections between pressure zones, as well as pressure impacts upstream and downstream of the interconnections.

10.2 HYDRAULIC DESIGN

10.2.1 Design Period

Although a 20-year design period is most frequently used for water treatment supply systems, it is recommended that longer design periods be used based on long-term population projections, given that water distribution systems have useful life expectancies well in excess of 20 years. Consideration should also be given to water quality deterioration arising from potential oversizing of the initial equipment.

Refer to *Section 3.4 – Design Flow* for more issues relating to water demand.

10.2.2 System Pressures

10.2.2.1 Maximum & Minimum Operating Pressures

All water mains, including those not designed to provide fire protection, should be sized after a hydraulic analysis based on flow demands and pressure requirements. The system should be designed to maintain a minimum pressure of 140 kPa (20 psi) at ground level at all points in the distribution system under maximum day demand plus fire flow conditions. The normal operating pressure in the distribution system should be approximately 350 to 480 kPa (50 to 70 psi) and not less than 275 kPa (40 psi). Pressures outside of this range may be dictated by distribution system size and/or topography. The designer should also consider pressure losses within serviced buildings due to the installation of equipment or appurtenances (water meters, backflow preventers, etc.) relative to the minimum operating pressure in the system.

The maximum pressures in the distribution system should not exceed 700 kPa (100 psi) to avoid damage to household plumbing and unnecessary water and energy consumption. When static pressures exceed 700 kPa (100 psi), pressure reducing devices should be provided on mains or service connections in the distribution system.

Refer to *Section 7.4.3 – Booster Pumping Stations* for more information regarding distribution system pressures.

10.2.2.2 Transient Pressures

The distribution piping system should be designed to withstand the maximum operating pressure plus the transient pressures to which it may be subjected. A thorough transient pressure analysis should be completed. Transient pressures are caused by rapid valve operation, pump start-up and shutdown or power failure. Pumping systems and stations should be designed to minimize surges and transient pressure conditions including negative pressures which may allow inflow of contaminants.

As a minimum allowance in the distribution system, it is recommended that pipes and joints be able withstand the maximum operating pressure plus the pressure surge that would be created by stopping of a water column moving at 0.6 m/s (2 ft/s). The pressure created by such an event will vary depending upon the diameter, wall thickness and pipe material used in the distribution system. Transient analysis should be undertaken for long transmission lines.

10.2.3 Friction Factors

For new pipe conditions, the designer should refer to the most recent versions of the following AWWA manuals:

- *Manual of Water Supply Practices M9 – Concrete Pressure Pipe*;
- *Manual of Water Supply Practices M11 – Steel Water Pipe: A Guide for Design and Installation*;
- *Manual of Water Supply Practices M23 – PVC Pipe: Design and Installation*;
- *Manual of Water Supply Practices M41 – Ductile-Iron Pipe Fittings*;
- *Manual of Water Supply Practices M45 – Fibreglass Pipe Design*; and
- *Manual of Water Supply Practices M55 – PE Pipe - Design and Installation*.

In evaluating existing systems for expansion, the C-factors should be determined by actual field tests wherever possible. Where these data are not available, common practice in Ontario has been to use the Hazen-Williams C-factors shown in Table 10-1 for the design of water distribution systems with pipes made of traditional materials, or when estimating pressure losses in the existing systems. The designer may choose to use other methods of calculating friction factors such as the Darcy-Weisbach equation or Manning equation.

10.2.4 Pipe Diameters

All watermains, including those not designed to provide fire protection, should be sized according to a hydraulic analysis based on flow demands and pressure requirements (*Section 10.2.2 – System Pressures*), as well as the depositional nature of the water with respect to long term watermain carrying capacity. Any departure from the minimum requirements listed below should be justified by hydraulic analysis. The actual inside pipe diameter should be used in the hydraulic calculations.

Table 10-1: C-Factors

DIAMETER - NOMINAL	C-FACTOR
150 mm (6 in)	100
200 mm – 250 mm (8 to 10 in)	110
300 mm – 600 mm (12 to 24 in)	120
Over 600 mm (over 24 in)	130

For systems designed to provide fire protection, the minimum size of watermains should be 150 mm (6 in) except beyond the last hydrant on culs-de-sac; in this case, pipes as small as 25 mm (1 in) may be used. Larger size mains may be necessary to allow the withdrawal of the required fire flow while maintaining the minimum pressure specified in *Section 10.2.2.1 – Maximum and Minimum Operating Pressures*.

Where fire protection is not to be provided, the minimum diameter of watermain in the distribution system should be 75 mm (3 in). The minimum size of watermains may also be dictated by the types of available equipment for cleaning watermains (e.g., swabs or pigs). In all cases, pipe diameters should be such that a flushing velocity of 0.8 m/s (2.6 ft/s) can be achieved for cleaning and disinfection procedures.

Refer to *Section 10.8 – Water Services* for more information on water service connections.

10.3 PIPE SYSTEM DESIGN

10.3.1 System Layout

Distribution system layouts are usually designed in one of three configurations, including arterial-loop systems, grid systems and tree systems.

Tree systems often have more dead-ends and the selection of this type of layout is generally not recommended.

Wherever possible, water distribution systems should be designed to eliminate dead-ends by making appropriate tie-ins or looping whenever practical in order to provide increased reliability of service and reduce stagnation and loss of disinfectant residual. Where dead-end mains can not be avoided, they should be designed with a means to provide adequate flushing and prevent stagnation such as a fire/flushing hydrant or blow-off.

10.3.2 Depth of Cover

With the exception of those watermains which will be taken out of service and drained in winter, the minimum depth of cover over watermains and service connections, including that portion on private property, should be greater than the depth of frost penetration. On services, this depth should be measured to the goose neck when it is vertical. If, for economic or practical reasons, it is not possible to install watermains below the frost line, the design should ensure that the watermain will be unlikely to freeze or be damaged by heaving or increased trench loads caused by frost penetration. Applicable temperature loss calculations should be performed to ensure the water will not freeze (*Section 12.2 – Climatic Factors*).

Large diameter watermains [over 300 mm (12 in)] without service connections and that are not dead-ends may be installed so that the frost-free depth corresponds with the springline of the pipe rather than the crown.

The increased external loads caused by frost may cause beam breaks in the pipe when bedding is non-uniform. For this reason, care should be taken in the selection of pipe materials, pipe classes, bedding types and the proper installation and compaction of the bedding to the springline.

10.3.3 Materials

10.3.3.1 Standards & Material Selection

All water contacting materials used in the construction and operation of drinking-water systems including pipe, fittings, valves, fire hydrants and materials used for the rehabilitation of watermains should meet all applicable quality standards described in *Section 3.26 – Chemicals and Other Water Contacting Materials*.

The designer should refer to the Ontario Ministry of Transportation *Ontario Provincial Standards for Roads and Public Works* (OPS) for the minimum recommended specifications for pipe, joints and fittings, bedding and cover materials.

Special attention should be given to selecting pipe materials which will protect against both internal and external corrosion.

In selecting a pipe material, the designer should consider the following factors:

- Trench foundation conditions;
- Location and other site specific factors;
- Soil conditions:
  - Corrosivity (need for cathodic protection);
  - Chemical composition and its effects on pipe material; and
  - Ability to provide thrust restraint.
- Drinking water corrosivity;
- Water temperature variations;
- Behaviour of the pipe material in the event of transient pressures and catastrophic failure;
- Costs (capital, operating, maintenance and other costs);
- Available labour skills; and
- Availability of suitable fittings and appurtenances acceptable to/or recommended by the pipe manufacturer, as well as spare parts and/or repair pieces.

When non-metallic pipes are selected, the designer should consider the use of pipe tracers for locating purposes.

10.3.3.2 Permeation by Organic Compounds

Where distribution systems are installed in areas of groundwater contaminated by organic compounds, materials which do not allow permeation of the organic compounds should be used for all portions of the system, including pipe, joint materials, O-rings, gaskets, hydrant leads and service connections (e.g., avoid HDPE where gasoline contamination may exist and PVC where dry cleaning solvent may be present).

10.3.3.3 Pipe Strength

Section 10.2.2 – System Pressures discussed distribution system operating and transient pressures. Buried watermains are also subjected to external loads imposed by the trench backfill, frost loading and superimposed loads (static and/or dynamic). The watermain pipe selected for a particular application should be able to withstand, with an acceptable margin of safety, all the combinations of loading conditions to which it is likely to be exposed.

Pipe strength designations and the methods for selecting the required pipe strength vary with the types of materials used. The designer should evaluate pipe supplier information and consult such references as CSA, ANSI/AWWA standards, OPS and design manuals.

10.4 FIRE HYDRANTS

10.4.1 Introduction

Fire hydrants should only be installed on watermains capable of supplying fire flow. For non-design requirements respecting fire hydrants (e.g., colour coding and maintenance) refer to the *Fire Code* (O. Reg. 388/97) made under the *Fire Protection and Prevention Act, 1997* and system municipality/owner or municipal requirements.

10.4.2 Location & Spacing

Fire hydrants should be provided at each street intersection, in the middle of long blocks and at the end of long dead-end streets. The required hydrant spacing decreases as the fire flow requirement increases. Hydrants should, therefore, be placed much closer together in high risk, high density areas, than in low density residential areas. Fire hydrant spacing ranges from 90 m to 180 m (300 to 600 ft) depending on the area being served. For more detailed information on hydrant spacing, refer to the latest edition of the Fire Underwriters Survey document *Water Supply for Public Fire Protection* and system municipality/owner or municipal requirements.

10.4.3 Hydrant Specifications

To minimize freezing problems, all fire hydrants used in Ontario should be the dry-barrel type and should conform to the latest edition of AWWA *Standard C502: Dry-Barrel Fire Hydrants*. All fire hydrants should be provided with adequate thrust blocking to prevent movement caused by thrust forces.

10.4.3.1 Hydrant Leads

The hydrant lead should be a minimum of 150 mm (6 in) in diameter. Auxiliary valves should be installed on all hydrant leads to allow for hydrant maintenance and repair with a minimum of disruption.

10.4.4 Hydrant Drainage

In areas where the water table will rise above the hydrant drain ports, the drain ports should be plugged. The barrels should be kept dry to prevent freezing damage to the barrel and water contamination.

Where hydrant drains are not plugged, they should drain to the ground if soil conditions permit, or to a dry well/drainage pit provided for that purpose.

10.5 FLUSHING & SWABBING

Flushing hydrants or devices are recommended for systems which are not capable of providing fire flow and for dead-ended watermains and areas where the degradation of water quality may be possible due to low consumption/flow conditions. Flushing devices should be sized to provide flows which will give a velocity of at least 0.8 m/s (2.6 ft/s) in the watermain being flushed. No flushing device should be directly connected to any sewer.

The designer should take into account operational procedures such as unidirectional flushing and watermain swabbing when designing looped watermain systems. In watermain loops, unidirectional flushing (strategic valve closing to direct flow to promote flushing velocity) may be required to produce the required flushing velocity. Valve placement to promote unidirectional flushing velocities should be considered in the design stage. This may require more valves than recommended in *Section 10.6 – Valves*.

Swabbing is another effective method used to clean watermains. For small diameter mains without hydrants, swab launching and retrieval ports need to be included in the design if swabbing is contemplated in the operations. Valve specifications also need to be considered. Butterfly valves cannot be used as they will trap the swab.

10.6 VALVES

The municipality/owner of the system should be consulted with respect to valve locations at intersections, line valve spacing, types of valves permitted, direction of rotation to open and the maximum size of valve permitted in a valve box.

10.6.1 Valve Placement

A sufficient number of valves should be provided on watermains to minimize inconvenience and contamination during repairs. Valves should be located at not more than 150 m (500 ft) intervals in commercial and industrial districts and at not more than one block or 240 m (800 ft) intervals in other districts. Where systems serve rural areas and where future development is not expected, the valve spacing should not exceed 2 km (1.25 mi).

In distribution system grid patterns, to minimize disruption during repairs, intersecting watermains should be equipped with shut-off valves as indicated in Table 10-2.

Table 10-2: Shut-Off Valves in Distribution System Grid Patterns

TYPE OF INTERSECTION	NUMBER OF VALVES
"T" Intersection	At least 2
Cross Intersection)	At least 3

10.6.2 Valve Standards

There are many different types of valves available and the designer should consider its application when selecting a valve. As a minimum, the recommendations of the manufacturer regarding appropriate valves for an application should be taken into account, with confirmation from the manufacturer that the valves conform to relevant AWWA standards. The designer should also ensure that open/close directions are consistent throughout the drinking-water system, and meets the requirements of municipality/owner.

For large diameter water supply or pressure zone isolation valves, consideration should be given to valved reduced-size bypass piping that can be used to avoid local stagnation and assist with open/close operations.

Valves 300 mm (12 in) in diameter or less may have access provided to the operating nut via a valve box and stem assembly, but it is recommended that all valves larger than 300 mm (12 in) in diameter be placed in valve chambers. All air release valves and drain valves should also be located in chambers. To minimize the number of chambers required, combinations of valves can be located within a single chamber.

10.6.3 Air Release & Vacuum Relief Valves

Air release/vacuum relief valves should be provided at high points in distribution and transmission lines (relative to the hydraulic gradient) where air can accumulate. The valves should conform to AWWA *Standard C512: Air Release, Air/Vacuum, and Combination Air Valves for Waterworks Service*.

The open end of an air release pipe from a manually operated valve should be extended to the top of the chamber and provided with a screened, downward-facing elbow if drainage is provided for the chamber. The open end of an air release pipe from automatic valves should be extended to at least 300 mm (1 ft) above grade and provided with a screened, downward-facing elbow to ensure it can not be flooded or blocked. Discharge piping from air relief valves should not connect directly to any storm drain, storm sewer or sanitary sewer.

Automatic air release valves should not be used in situations where flooding of the access hole or chamber may occur.

Where the need for an automatic air release valve is uncertain, a manual air release valve or hydrant can be installed initially and later replaced with an automatic valve if significant air accumulations are found.

10.6.4 Drain Valves

With large diameter mains, drain valves positioned at low points may be required to permit main repairs. Small diameter watermains can generally be drained through hydrants by using compressed air and/or pumping.

10.7 SAMPLING STATIONS

The designer should consider the provision of dedicated sampling stations within the distribution system to facilitate water quality monitoring. In the selection of locations for sampling sites, the designer should consider challenging conditions within the system such as increased hydraulic retention times, temperature variations, materials of construction, etc.

10.8 WATER SERVICES

In selecting the diameter of a service connection, the designer should consider such factors as the following:

- Peak water consumption in the building serviced;
- Total length of service line from the watermain to the building connection;

- Watermain pressure under peak demand conditions (*Section 10.2.2.1 – Maximum and Minimum Operating Pressures*);
- Loss of head resulting from length and condition of pipe, fittings, and backflows preventers and meters; and
- Required pressure at point of use.

The recommended minimum size of service line for single-family residences is 19 mm (¾ in). Larger residences and buildings located far from the watermain connection should have a 25 mm (1 in) or larger service. For details on proper water sizing of service lines, refer to a publication such as AWWA *Manual of Water Supply Practices M22 – Sizing Water Service Lines and Meters*.

The designer should consider the provision of two services with an isolation valve between the connections to help ensure redundancy to sensitive users (such as hospitals, day cares, long-term care facilities, etc.) in the event of a service line failure.

Water service lines should be constructed of materials acceptable under the Part 7 of Division B of the *Building Code* (O. Reg. 350/06) made under the *Building Code Act, 1992* and should conform to AWWA *Standard C800: Underground Service Line Valves and Fittings*. Municipalities should be consulted regarding local preferences and requirements. All water services should be equipped with a corporation stop and a curb stop. The curb stop should be provided with a curb box.

Where booster pumps are installed on residential service from the public water supply main, an air gap backflow preventer should be provided.

10.9 RESTRAINT

Adequate restraint must be provided in water distribution systems to prevent pipe movement and subsequent joint failure. In the case of non-restraining mechanical and/or slip-on joints, this restraint should be provided by adequately sized thrust blocks positioned at all plugs, caps, tees, line valves, reducers, wyes, hydrants and bends deflecting 22½° or more. Depending upon internal pressures, pipe sizes, pipe material and soil conditions, bends of lesser deflection may also require thrust blocking. Thrust block material should resist deterioration from moisture or corrosive soil.

An alternative approach that can be used to prevent joint failure is either to use pipe and jointing methods capable of resisting the forces involved (such as welded steel pipe, or polyethylene pipe with thermal butt-fusion joints) or use joint restraining methods, such as metal tie rods, clamps or harnesses.

In designing thrust blocks and other restraint systems, the designer should remember that transient pressures should be added to the normal operating pressures when calculating the thrust forces (if velocity of flow is very high, dynamic thrust should also be calculated); adequate corrosion protection should be provided for external clamps and tie rods; the safe bearing values of soils should be reduced substantially from textbook figures if shallow trenches are used or if bearing against disturbed soils. For further discussion of thrust blocking and joint restraint design, refer to the pipe manufacturer catalogue and other sources such as AWWA standards, OPS, textbooks and watermain design manuals.

10.10 INSTALLATION & REHABILITATION OF WATERMAINS

10.10.1 Installation Standards & Technologies

Installation specifications should incorporate the provisions of appropriate AWWA standards, the OPS and/or manufacturer recommended installation procedures. Pressure and leak testing should be included. The pipe installation should also allow for thermal expansion.

The designer should consider site specific conditions when selecting an installation technology. In certain instances, it may be more appropriate to use trenchless technologies, such as directional drilling, tunnelling or micro-tunnelling.

10.10.2 Bedding

Continuous and uniform bedding should be provided in the trench for all buried pipe. Backfill material should be tamped in layers not exceeding 150 to 250 mm (6 to 10 in) around the pipe and to a sufficient height above the pipe to adequately support and protect the pipe. Large stones [75 mm (3 in) or greater] found in the trench should be removed for a depth of a least 150 mm (6 in) below the bottom of the pipe.

Bedding materials and methodology should conform to the appropriate AWWA and OPS specifications, and should be no less than as recommended by the pipe manufacturer.

10.10.3 Disinfection

New, cleaned and repaired watermains should be disinfected in accordance with AWWA *Standard C651-05: Disinfecting Water Mains* or an equivalent procedure [as required by the *Procedure for Disinfection of Drinking Water in*

Ontario (Disinfection Procedure)]. The specifications should include detailed procedures for the flushing, disinfection and microbiological testing of all watermains before being put into service.

10.10.4 Corrosion

In areas where aggressive soil conditions are suspected, analyses should be performed to determine the actual aggressiveness of the soil. If soils are found to be aggressive, metallic watermains should be protected, such as by encasement of the watermain in polyethylene or concrete, application of corrosion protection tape, provision of cathodic protection or by using corrosion resistant watermain materials. Consideration should be given to protection against galvanic corrosion when appurtenances and metal pipe of differing materials are connected.

Refer to *Section 5.18 – Internal Corrosion Control* for information on the prevention of internal corrosion by water quality adjustment or amendment.

10.10.5 Pipe Rehabilitation

There are a number of methods to rehabilitate water distribution pipes with new or improved technologies and materials being developed every year. The designer should ensure the use of the most up-to-date information when making decisions about pipe rehabilitation. Two leading sources of information are the AWWA and the North American Society for Trenchless Technologies (NASTT). The *InfraGuide*[17]: *National Guide to Sustainable Infrastructure report Selection of Technologies for the Rehabilitation or Replacement of Sections of a Distribution System* (2003) provides an overview of best practices.

Rehabilitation methods include slip-lining, close fit slip-lining, cured-in-place lining, pipe bursting, horizontal drilling, micro-tunneling, internal joint seals and spray lining (cement or epoxy). Only materials with NSF/ANSI Standard 61: *Drinking Water System Components - Health Effects* certification should be used (*Section 10.3.3.1 – Standards and Material Selection*). Where iron pipe has been cleaned by pigging, the cleaned surfaces should be protected with a coating or lining so as to prevent severe red water problems and further corrosion.

When selecting a rehabilitation or replacement technology the designer should consider the following factors:

- Construction issues such as safety, operability, cost and efficiency;

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[17] InfraGuide operated from 2001 to 2007 as a partnership between the Federation of Canadian Municipalities (FCM), the National Research Council of Canada (NRC) and Infrastructure Canada (IC)

- Cost of mobilizing specialized equipment and personnel;
- Risk of undertaking (or not undertaking) the project, focusing on the safety of the water supply, environmental and construction issues;
- Depth of the watermains and presence of permafrost which may limit applicability of technologies;
- Density of water services if excavations are required to reconnect each service; and
- Existing customer service needs during the rehabilitation project.

10.11 SEPARATION DISTANCES FROM CONTAMINATION SOURCES

10.11.1 General

This section describes good engineering and construction practice and will reduce the potential for any health hazard from water-borne disease or chemical poisoning in the event of the occurrence of conditions conducive to possible contaminated groundwater flow into the water distribution system.

Contaminated ground and surface water may enter the water distribution system at leaks or breaks in components such as piping, vacuum air release valves, blow-offs, fire hydrants, meter sets, and outlets with the occurrence of a negative internal or positive external pressure condition. Water pressure in a part of the system may be reduced to a potentially hazardous level due to shutdowns in the system, main breaks, heavy fire demand, high water usage, pumping, storage or transmission deficiency and negative surge pressures.

The relative location of sewers and watermains (including appurtenances) and types of material used for each system are important considerations in designing a system to minimize the possibility of contaminants entering the water distribution system. The use of and adherence to good engineering practice will reduce the potential for health hazards.

10.11.2 Sewer & Watermain Parallel Installations

Sewers/sewage works[18] and watermains located parallel to each other should be constructed in separate trenches.

When it is impossible or not practical to maintain a separate trench and a minimum separation distance, the crown of the sewer should be at least 0.5 m

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[18] Includes sanitary sewers and forcemains, storm or combined sewers and forcemains, sewer access/maintenance holes and all appurtenances and fittings

(20 in) below the invert of the watermain, and separated by in-situ material or compacted backfill. Also, joints should be offset as much as possible between sewers and watermains.

Where this vertical separation cannot be obtained, the sewers should be constructed of watermain quality pipe, pressure tested in place at a pressure of 350 kPa (50 psi) without leakage using the testing methodology in *Ontario Provincial Standard Specification 701* (OPSS 701) of the OPS.

In rock trenches, drainage should be provided to minimize the effects of impounding of surface water and/or the leakage from sewers in the trench.

10.11.3 Crossings

Watermains should cross above sewers wherever possible. Whether the watermain is above or below the sewer, a minimum vertical distance of 0.5 m (20 in) between the outside of the watermain and the outside of the sewer should be provided to allow for proper bedding and structural support of the watermain and sewer pipe. Sufficient structural support for the sewer pipes should be provided to prevent excessive deflection of the joints and settling. The length of water pipe should be centred at the point of crossing so that joints in the watermain will be equidistant and as far as possible from the sewer, crossing perpendicular if possible.

10.11.4 Service Connections

Wherever possible, the construction practices outlined in Part 7 of Division B of the *Building Code* (O. Reg. 350/06) made under the *Building Code Act, 1992* should be applied to sewer and water services.

10.11.5 Tunnel Construction

If a tunnel is of sufficient size to permit a person to enter it, a sewer and watermain may be placed through the tunnel providing the watermain is hung above the sewer. If the tunnel is sized only for the pipes or is subject to flooding, the sewers should be constructed of watermain quality pipe, pressure tested in place according to OPSS 701 of the OPS at a pressure of 350 kPa (50 psi) without leakage.

10.11.6 Design Factors

When local conditions do not permit the spacing outlined above or other conditions indicate that detailed investigations are warranted, the following non-inclusive list of factors should be considered as a guide:

- Materials, types of joints and identification for water and sewer pipes;

- Soil conditions (e.g., in-situ soil and backfilling materials and compaction techniques);
- Service and branch connections into the watermain and sewer lines;
- Compensating variations in the horizontal and vertical separations;
- Space for repair and alterations of water and sewer pipes;
- Off-setting of pipes around access/maintenance holes;
- Location of groundwater table and trench drainage techniques;
- Other sanitary facilities such as septic tanks and tile fields; and
- Any other factor that may be relevant to the design.

10.11.7 Valve, Meter & Blow-Off Chambers

Chambers, pits or access holes containing valves, blow-offs, meters or other such appurtenances to a distribution system, should not be located in areas subject to flooding or in areas of high groundwater. Where such locations are unavoidable, measures should be taken to prevent infiltration of surface water or groundwater. Chambers or pits should drain to the ground surface, to absorption pits underground, or to a sump within the chamber where the groundwater level is above the chamber floor. Chambers should be lockable to avoid safety and vandalism concerns. Protection against freezing (frost strapping or other means) and frost heave of the chamber should be provided.

The designer should consider venting and drain appurtenances between line valves so as to eliminate air locks during watermain disinfection procedures and watermain restoration procedures.

The chambers, pits and access holes should not connect directly to any sanitary sewer, but may be connected to storm sewers provided backflow prevention is included. Blow-offs and air release valves should not be connected directly to any sewer.

10.11.8 Unacceptable Installations

No water pipe should pass through or come in contact with any part of a sewer access/maintenance hole, septic tank, tile field, subsoil treatment system or other source of contamination.

10.12 SURFACE WATER CROSSINGS

10.12.1 Above-water Crossings

The pipe should be adequately supported and anchored, protected from damage and freezing, and accessible for repair or replacement.

10.12.2 Underwater Crossings

A minimum cover of 0.6 m (2 ft) should be provided over the pipe. Consideration should be given to the potential for the stream bottom to change as a result of scour or dredging. When crossing water courses which are greater than 5 m (16 ft) in width, the following should be provided:

- The pipe should have flexible, restrained or welded watertight joints;
- Valves should be provided at both ends of water crossings so that the section can be isolated for testing or repair; the valves should be easily accessible and not subject to flooding; and
- Permanent taps or other provisions to allow insertion of a small meter to determine leakage and obtain water samples should be made on each side of the valve closest to the supply source.

Where there is any likelihood of marine travel, the designer should refer to the *Navigable Waters Protection Act*.

10.13 BACKFLOW & CROSS-CONNECTIONS CONTROL

10.13.1 Cross-Connections

Precautions should be taken in the design of water distribution and plumbing systems to prevent the entrance of contaminating materials into the drinking-water system.

Contaminants can enter water supply systems from various sources including cooling water systems, pump seal water systems, industrial process piping and groundwater. No steam condensate, cooling water from engine jackets or water used in conjunction with heat exchange devices should be returned to the drinking-water supply.

Deterioration can also occur from entry into the system of untreated water due to watermain de-pressurization conditions allowing contamination through vents or other appurtenances.

To control contamination from non-drinking water piped systems, cross-connection control/backflow prevention measures and/or equipment are necessary.

For information on cross-connection control, the designer should refer to the AWWA Manual of Water Supply Practices M14 – Recommended Practice for Backflow Prevention and Cross-Connection Control and USEPA Cross-Connection Control Manual, 2003

10.13.2 Backflow Prevention Equipment

There are several types of backflow prevention devices available including air gaps, double check valve assemblies, reduced pressure principle devices, dual check valves, atmospheric vacuum breakers and pressure vacuum breakers. For applications involving health hazards, only air gaps or reduced pressure principle devices should be used.

For information on backflow prevention equipment, the designer should refer to:

- Applicable municipal by-laws;
- *Building Code* (O. Reg. 350/06) made under the *Building Code Act, 1992*;
- Canadian Standards Association (CSA) standards *CAN/CSA-B64 SERIES-01 Backflow Preventers and Vacuum Breakers*, *CAN/CSA-B64.10-01/B64.10.1-01 Manual for the Selection and Installation of Backflow Prevention Devices/Manual for the Maintenance and Field Testing of Backflow Prevention Devices*, and *B64.10S1-04/B64.10.1S1-Supplement #1 to CAN/CSA-B64.10-01/CAN/CSA-B64.10.1-01*;
- AWWA *Standard C510: Double Check Valve Backflow Prevention Assembly and* AWWA *Standard C511: Reduced-Pressure Principle Backflow Prevention Assembly;* and
- AWWA *Manual of Water Supply Practices M14 – Recommended Practice for Backflow Prevention and Cross-Connection Control.*

10.14 WATER LOADING STATIONS & TEMPORARY WATER SERVICES

Water loading stations and temporary water services should be protected against potential backflow, which may allow contamination to enter the distribution system, in accordance with the requirements of *CAN/CSA-B64.10-01/B64.10.1-01 Manual for the Selection and Installation of Backflow Prevention Devices/Manual for the Maintenance and Field Testing of Backflow Prevention Devices*.

Vessels and water hauling equipment should be equipped with an air gap or reduced pressure type backflow preventer in accordance with *CAN/CSA-B64.10-01/B64.10.1-01 Manual for the Selection and Installation of Backflow Prevention Devices/Manual for the Maintenance and Field Testing of Backflow Prevention Devices*.

CHAPTER 11

RESIDUALS MANAGEMENT

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CHAPTER 11

RESIDUALS MANAGEMENT

This chapter provides guidance for the handling, treatment and environmentally acceptable disposal of water treatment process waste residuals. A discussion of all types of residuals and treatment technologies is beyond the scope of this guideline, however, a brief overview of the types of plant waste residuals and treatment options commonly used in Ontario is provided.

11.1 GENERAL

Provisions should be made for proper treatment and disposal of water treatment plant process residuals such as clarification/sedimentation sludge, softening sludge, iron/manganese removal sludge, filter backwash water, filter-to-waste, brine, wastes from fluoride or arsenic removal processes, slow sand or diatomaceous earth filtration processes, membrane reject water, spent carbon and ion exchanger regenerants, pump seal water waste, laboratory wastes and on-line instrument wastes.

Most residuals produced by a water treatment plant will require treatment. The degree of treatment necessary will be dictated by the disposal method or, in the case of a discharge to the environment, the assimilative capacity of the receiving water body (surface or ground water). The effluent quality criteria for discharge to the environment should be established through consultation with the appropriate ministry Regional Office. For wastewater flow streams that are regulated by discharge quality limits [as specified in requirements such as a *Certificate of Approval* (C of A) *Drinking Water Works Permit* (DWWP) / *Municipal Drinking Water Licence* (Licence) or *Sewer Use By-Law*] it is recommended that appropriate process monitoring devices be provided to allow operators to react to wastewater treatment process upsets. Designers should review any relevant wastewater effluent criteria pertaining to the facility and design wastewater treatment processes to meet such requirements.

The impact of and issues related to residuals management should be considered at the time of water treatment process evaluation and selection. Due to likely heavy wear, provisions should be made to ensure reliability and redundancy of residuals handling equipment.

For information on residuals management, the designer may refer to the AwwaRF report *Water Treatment Plant Residuals Engineering* (Project #2934), 2006.

11.2 SPECIFIC WATER TREATMENT PROCESS RESIDUALS

11.2.1 Sedimentation/Clarification

Treatments for sludges from the sedimentation/clarification process should be designed to reduce the volume for disposal. For large plants, mechanical dewatering methods such as centrifuges, rotary drum thickeners or filter presses may be appropriate. For medium and small plants with sufficient land area available, the natural freeze-thaw method may be considered.

Sludge may be directed to a sanitary sewer where the sewer and the sewage treatment plant have sufficient hydraulic and treatment capacity and with the agreement of the municipality/owner.

11.2.2 Chemically-Assisted Granular Media Filtration

This process produces high volume, short duration wastewater flows (backwash) that require handling in a suitably sized surge/equalization tank (*Section 11.4.1 – Flow Equalization*). Surge tank discharges may be directed to a sanitary sewer where the sewer and the sewage treatment plant have sufficient hydraulic and treatment capacity and with the agreement of the municipality/owner.

Where limited sewage treatment capacity exists, the waste flow may be directed to a holding tank and allowed to settle before the supernatant is discharged to a sanitary sewer and the sludge removed for further treatment. Where sewer discharge is not possible and appropriate effluent quality control measures are provided, direct discharge to a receiving water body may be acceptable.

When these options are not available or are limited, the surge tank discharges should be directed for further treatment.

11.2.2.1 Recycling Treated Backwash Water

Recycling of effluent (supernatant) from backwash treatment facilities involves consideration of special hazards due to the potential for increased concentration of pathogens in the water. This may be especially significant for pathogen impacted raw water sources. Where this process is incorporated into the design of the treatment facility, the designer should ensure that the recycle stream after treatment is directed to the head of the water treatment plant. Backwash water treatment should be designed to provide highly efficient particulate removal by incorporating such measures as low clarifier overflow rates [3.0 m/h (1.2 USgpm/ft^2)] with polymer addition, or membrane filtration so that the increased concentration of viable cysts and contaminants as a result of the recycling process is minimized. The use of a disinfecting agent effective for the inactivation of cysts, typically ultraviolet light, is recommended in the recycling line. In addition, filter backwash water should not be recycled when the raw water contains excessive algae or when disinfection by-product levels in the distribution system may exceed allowable levels. Monitoring of the recycle stream quality may also be necessary.

11.2.3 Membrane Filtration

Chemically unaltered membrane reject water may be discharged without treatment provided it meets the effluent quality criteria for discharge to the environment established through consultation with the appropriate ministry Regional Office. Where this option is not available, the concentrate or reject should be directed to a treatment facility as described in *Section 11.2.1 – Sedimentation/Clarification*.

Disposal options for ***membrane backwash*** residuals are similar to those for conventional water treatment plants, and typically include the following:

- Discharge to the sanitary sewer;
- Treatment with supernatant recycle and solids disposal; and
- Discharge to a suitable surface water body.

All membrane plants require periodic chemical cleaning. Where possible, chemical cleaning residuals should be treated on-site and discharged to either a sanitary sewer or holding tank for further disposal. Oxidants such as chlorine used in the chemical cleaning process should be quenched prior to discharge, and acids and bases should be neutralized. The use of other chemicals, such as surfactants or proprietary cleaning agents, may require additional treatment.

The rinse water applied to the membranes after the cleaning process may also represent a chemical waste and thus may require treatment prior to discharge. Although the rinse water increases the volume of the chemical cleaning residuals, this increase can be balanced somewhat by the recovery and reuse of a significant portion of the cleaning solutions.

11.2.4 Iron & Manganese Removal

Backwash waste and sludge from iron and manganese removal systems treating groundwater can be handled by discharge to a sanitary sewer, or to a holding tank for decanting, recycling of supernatant to the head of the plant, and trucking sludge for off-site disposal. Discharge to a sanitary sewer should conform to the requirements of *Section 11.3.1 – Disposal to Sanitary Sewer*. The designer should be aware that biological activity in the aquifer close to the well over time may cause a change in the incoming water characteristics and force the abandonment of the recycling option.

11.2.5 Ion Exchange Processes

Waste from ion exchange plants, ion exchange softening, demineralization plants or other plants which produce a brine may be disposed of through the sanitary sewer, where permitted, and where the impact on sewage treatment processes is negligible. A surge/equalization tank with discharge control may be needed.

Where discharging to a sanitary sewer is not available, a holding tank should be provided to facilitate off-site disposal.

11.2.6 Precipitative Softening

Sludge from precipitative softening processes varies in quantity and in chemical characteristics depending on the softening process and the chemical characteristics of the water being softened. The designer should consider that the quantity of sludge produced may be much larger than indicated by stoichiometric calculations. Methods of treatment and disposal include lagoons, land application, mechanical dewatering and landfilling. Lime sludge drying beds are not recommended.

Discharge of lime sludge to sanitary sewers should be avoided and may only be used in situations where the sewage system capacity is adequate to accommodate the lime sludge.

11.3 DISPOSAL OPTIONS

11.3.1 Disposal to Sanitary Sewer

Discharges may be directed to a sanitary sewer where the sewer and the sewage treatment plant have adequate hydraulic and treatment capacity and subject to the agreement of the municipality/owner. Disposal of plant process wastewater and sludges to municipal sewers may be limited by municipal by-laws, and consultation with the sewage system operating authority is needed.

The capacity of the sanitary sewer system and sewage treatment plant may be such that surge/holding tanks are needed.

11.3.2 Land Application

The *Nutrient Management Act, 2002* (NMA) addresses materials containing nutrients applied to agricultural land. It includes provisions for the development of strong standards for all land-applied materials containing nutrients and a registry system for all land applications. Land applied materials include sewage biosolids and other non-agricultural source materials. The *General* (*O. Reg. 267/03*) regulation under the *NMA* sets out the application rates and other conditions relating to the spreading of biosolids e.g., separation distances, groundwater and surface water protective measures, and biosolids handling and spreading practices.

Sludges from municipal drinking-water systems may be utilized as an organic soil conditioner. When considering this option, the designer should refer to Ministry publications *Guidelines for Utilization of Biosolids and Other Wastes on Agricultural Lands (*PIBS 3425e*)*, developed in conjunction with the Ontario Ministry of Agriculture, Food and Rural Affairs, and *Guide to Applying for a Certificate of Approval to Spread Sewage and Other Biosolids on Agricultural Lands (Organic Soil Conditioning)* (PIBS 3681e). The local Ministry District Office is responsible for issuing a C of A under Part V, Section 27 of the *Environmental Protection Act* (EPA). Applications may require review by the Biosolids Utilization Committee.

11.3.3 Disposal in a Landfill

Drinking-water system residuals disposed of in a sanitary landfill must first have solids concentrated to a semisolid or cake form. Transportation of screenings, dewatered sludge or other final residue solids to a municipal landfill site for ultimate disposal requires Director approval under Part V, Section 27 of the EPA and Director approval of the Ministry Environmental Assessment and Approvals Branch (EAAB). All sites (whether or not requiring public hearings or subject to the EPA) are processed by the EAAB Waste Unit.

11.4 TREATMENT OPTIONS

The choice of residuals treatment process will depend on the raw water quality, the treatment plant processes as well as the discharge and ultimate disposal requirements. In cases where satisfactory operating data to confirm the suitability of a particular treatment process does not exist for a given residuals stream, pilot testing may be needed.

11.4.1 Flow Equalization

The purpose of a flow equalization or surge tank is to contain large volumes of wastewater which accumulate in a short period of time and to allow it to be introduced to a subsequent treatment process at a constant rate.

The surge tank should be designed to receive backwash water, filter-to-waste flows and sedimentation blowdown. The tank should be sized to accept the anticipated backwash plus filter-to-waste volume from a minimum of two filters and should be increased according to the number of filters. The surge tank should be equipped with an air or mechanical mixing system to keep solids in suspension.

The surge tank should also be equipped with transfer pumps continuously discharging at constant rate to a clarifier. The pumps should be sized to meet the designed surface overflow rate for the applicable type of clarifier (*Section 5.5 – Clarification* and Chapters 8 and/or 10 of the Design Guidelines for Sewage Works).

The surge tank may also allow the wastewater to be directed to the sanitary sewer at a uniform rate, if this option is available.

11.4.2 Sedimentation/ Clarification

Increasing the concentration of solids in the waste stream may be accomplished by gravity settling, with or without plate or tube settlers, dissolved air flotation, ballasted clarification or other sedimentation/clarification processes. Refer to *Section 5.5 – Clarification* for more information regarding the design of these treatment processes.

The supernatant from the sedimentation tank may be returned to the source, upon consultation with the appropriate ministry Regional Office, or be directed to the sanitary sewer (*Section 11.3.1 – Disposal to Sanitary Sewer*). The settled sludge may be transferred to a thickener, a holding tank for off-site disposal, or directed to a sanitary sewer.

11.4.3 Thickening

Sludge thickening is performed primarily for reduction in the volume of sludge which will require subsequent treatment. This step may be combined in a single tank with the sedimentation/clarification process. Thickening tanks may also serve as equalization facilities to provide a uniform feed to the dewatering step. A liquid polymer(s) feed system may be provided to chemically condition the sludge and assist sludge thickening.

Historically, gravity thickening has been the process most often used in the water industry. Gravity thickening is typically accomplished in a circular tank designed and operated similarly to a solids-contact clarifier or sedimentation tank (*Section 5.5 – Clarification*). Solids loading rates are typically between 20 and 80 kg/(m^2·d) [4 to 16 lb/(ft^2·d)] for coagulant sludges. Where mechanical scraper units are used for sludge removal, the velocity of the scraper should not exceed 18.0 m/h (60 ft/h) to prevent resuspension of the settled sludge.

The thickened sludge may be transferred for further treatment or disposal.

Sludge thickening ability can be highly variable and pilot testing may be needed for establishing design criteria for satisfactory performance. Seasonal changes in the effectiveness of these processes should also be considered.

11.4.4 Dewatering

Methods of dewatering include the following:

- Air/ gravity drying processes:
    - Sand drying beds;
    - Freeze-thaw beds;
    - Solar drying beds; and
    - Vacuum assisted drying beds.
- Mechanical dewatering processes:
    - Belt filter presses;
    - Centrifuges; and
    - Pressure filters.

A complete discussion on each of these dewatering processes is beyond the scope of these guidelines. Some general recommendations, however, are provided in the following sections.

11.4.4.1 Air/ Gravity Drying Beds

Decanting and drainage systems should be provided. Climate, drainage discharge location, required solids concentration and slump characteristics requirements of the final pre-selected solid waste disposal site should be considered. Sludge layers should be kept thin to maximize drying rates.

Sand drying beds dewater primarily by gravity drainage of water from the sludge by placing the sludge on a sand medium. They are more effective for lime sludges than for coagulant sludges. Loading rates are typically between 1.0 and 2.4 kg/m^2 (0.2 and 0.5 lbs/ft^2). Draining time is typically 3 to 4 days. Applied sludge depth should be 200 to 750 mm (8 to 30 in) for coagulant sludges and 300 to1200 mm (12 to 48 in) for lime sludges.

Freeze-assisted drying beds use a freeze-thaw cycle to break the molecular bonds between the water and the sludge which greatly enhances the dewatering rate. These systems are more suitable for dewatering coagulant sludges in cold climates. Freeze-thaw systems should be designed with two (2) drying beds, each sized to accommodate one (1) year of sludge storage.

Solar drying beds use asphalt or concrete as a sub-base for dewatering of sludge. The heat promotes faster drying. This process does not have widespread applicability in Ontario due to the local climate.

In vacuum-assisted drying beds, suction draws water from the underside of rigid, porous medial plates upon which the residuals are placed. Frequent plate cleaning and chemical sludge conditioning is typically required for this type of process.

11.4.4.2 Mechanical Dewatering Processes

Belt and diaphragm filter presses dewater residuals by sandwiching sludge between two porous belts and are suitable for dewatering coagulant sludges to 15% to 20% and lime sludges to 50% to 60%. The applied pressure is typically in the 600 to 1,500 kPa (87 to 218 psi) range. Roller bearings should be designed to have a service life (***L10***) of approximately 300,000 hrs. A polymer conditioning system should be provided for all belt filter presses. Consideration should also be given to desired cake solids content, conditioning requirements, pressure requirements, belt speed, belt tension, belt type and belt mesh size.

Centrifuges dewater residuals by forcing water from solids under high centrifugal forces. Both co-current and counter-current designs are available. Design criteria will be proprietary in nature and the manufacturer should be consulted in cases where a centrifuge is being considered. A polymer conditioning system should be provided for all centrifuge systems.

Similar to air/gravity dewatering systems, decanting and drainage systems should be provided and the required solids concentration and slump characteristics required for the final pre-selected solid waste disposal site should be considered.

11.4.5 Lagoons

Where residuals treatment through lagoons is proposed, a minimum of two cells should be provided, each capable of independent operation. Each cell should be sufficiently large to hold twelve months' sludge production plus a minimum of one day liquid waste volume.

Typically, the lagoon design should allow for sludge depths of 0.5 to 0.75 m (1.6 to 2.5 ft), supernatant depths of 0.5 to 0.75 m (1.6 to 2.5 ft) and allow for ice cover as appropriate to local conditions.

Inlet piping should be designed to distribute the incoming waste uniformly and minimize disruption of the settled sludges. The piping should be designed to be free draining to reduce the possibility of frost or ice damage in winter.

Outlet piping should be designed to permit displacement operation during winter, and should be free draining. Each cell should have a supernatant decant system which is adjustable.

The required effluent quality criteria for lagoon discharge to the environment (including subsurface infiltration) should be established through consultation with the appropriate ministry Regional Office. The design for lagoons should provide for:

- Location free from flooding;
- Where necessary, dikes, deflecting gutters or other means of diverting surface water so that it does not flow into the lagoon;
- A minimum usable depth of 1.5 m (5 ft);
- Adequate free board of a least 0.6 m (2 ft);
- Adjustable decanting device;
- Effluent sampling point;
- Adequate safety provisions;
- Parallel operation; and
- A minimum of two cells, each with appropriate inlet/outlet structures to facilitate independent filling/dewatering operations.

11.5 RESIDUALS PIPING DESIGN

The designer should consider the provision of an emergency filter backwash residuals by-pass overflow to allow treatment plant operations to continue at all times.

Piping for process residual streams should not pass through treated water retaining structures. Appropriate backflow protection should be provided on residuals piping as needed to protect the quality of the treated water.

Residuals piping should be provided with adequate cleanouts and provision for flushing. A minimum velocity of 0.5 m/s (1.6 ft/s) is recommended for all wastewater lines.

11.6 RADIOACTIVE MATERIALS

Where radioactivity has been detected during source water characterization, the treatment process may accumulate radioactive materials in waste residual streams to a level that requires special handling provisions. The designer should refer to the *Guidelines for the Management of Naturally Occurring Radioactive Materials* (NORM) available from the Health Canada website: http://www.hc-sc.gc.ca.

CHAPTER 12

CHALLENGING CONDITIONS

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CHAPTER 12

CHALLENGING CONDITIONS

This chapter presents design guidelines, suggestions and ideas which may assist in the application and design of alternate technologies for underground servicing of areas that are affected by challenging conditions. For more detailed information on this subject the designer should refer to the American Society of Civil Engineers/ Canadian Society for Civil Engineers (ASCE/CSCE) Cold *Regions Utilities Monograph, 1996* (formerly *Cold Climate Utilities Deliver Design Manual*, Environment Canada) available from the ASCE bookstore website: http://www.asce.org.

12.1 GENERAL

Challenging conditions may be a result of: climate, geology, hydrogeology, location (remoteness) of the area, topography or any combination of these factors. These challenging conditions are often associated with northern communities, but can also occur in urban areas where above ground piping is necessary (i.e., bridge crossings or over permafrost) and/or shallow buried obstructions such as culverts that cause pipe to be placed in the frost zone.

12.2 CLIMATIC FACTORS

The main climatic elements that can affect low ground temperatures are cold air temperatures and the amount of snow cover. With below freezing temperatures, the designer must determine whether the conditions are such that the proposed water service will freeze or be otherwise negatively impacted. Historical information on Ontario climate is available from the Environment Canada website: http://climate.weatheroffice.ec.gc.ca. Design temperature data are also provided in the *Supplementary Standard SB-1* of the *Building Code* (O. Reg. 350/06) made under the *Building Code Act, 1992*.

The main indicator utilized to determine the relative "air coldness" of an area is the "Freezing Index". The "Freezing Index" is defined as the number of degree days above and below 0ºC (32ºF) between the highest point in autumn and the lowest point the next spring on the cumulative degree-day time curve for one freezing season. It is recommended that the designer consider the coldest month.

The climatic factor most seriously impacting the design, cost and operation of piped water services is frost. The depth to which it penetrates depends upon the Freezing Index, the frost susceptibility of the soil and the thermal conductivity of the soil. The designer should refer to the ASCE/CSCE *Cold Regions Utilities Monograph, 1996.*

Another factor to be considered in any design is frost heave. As the water in the pores of the soil freezes, there is an associated increase in the volume of the soil of up to 5%. If ice lenses form in the soil, much greater increases may occur. Any service system that is to be constructed within the frost zone must be designed with consideration given to the rise of the ground surface due to frost action.

For more information regarding frost and freezing, the designer should refer to the National Research Council of Canada (NRC), Institute for Research in Construction (http://irc.nrc-cnrc.gc.ca) and the Ontario Ministry of Transportation.

12.3 GEOLOGICAL FACTORS

The predominant geological factor which can have an effect on service design conditions is the presence of rock and its proximity to the surface. This phenomenon is common in many areas of the Province and predominant in Northern Ontario where the main geological feature is the Precambrian formation of the Canadian Shield.

Other factors of concern respecting the geology of the northern parts of the Province, and hence the design of water services, are:

- The presence of ***muskeg*** which can be found in depths varying from less than 0.3 m (1 ft) to in excess of 3.0 m (10 ft);
- Soil classification and frost susceptibility;
- Soil thermal conductivity;
- Soil chemistry (i.e., acidic and alkali soils); and
- The presence of a high water table.

12.4 LOCATION (REMOTENESS)

In certain northern regions of the province, the location of the community to be serviced may be a factor in the design. Access to the site may be difficult, limited and/or expensive due to the lack of adequate road or rail transportation.

These access problems affect the supply of materials such as chemicals, construction equipment, and replacement parts, as well as servicing. In these areas, the designer should ensure that the servicing methods are adapted as simply as possible to suit local conditions. If special fittings and accessories are required that may be difficult to obtain, replace and service, this should be considered at the design stage and spares purchased during construction.

12.5 PERMAFROST

Permafrost is defined as soil, bedrock or other material that has remained below 0°C (32°F) for two or more years. Continuous Permafrost occurs in areas that are underlaid by permafrost with no thawed areas. Discontinuous Permafrost occurs in an area underlain mostly by permafrost but containing small areas of unfrozen ground.

In Ontario, a state of discontinuous permafrost exists north of the line drawn from the southern tip of Hudson Bay, westerly to the point where the 53°N parallel intercepts the Ontario western boundary, to the 55°N parallel. More information on the distribution of permafrost in Ontario is available from Natural Resources Canada (http://atlas.nrcan.gc.ca).

Passive construction is usually used in permafrost conditions. This maintains the state of frozen permafrost by constructing insulated water services. Permafrost conditions will not likely be met in any but the most remote northern areas of the Province.

12.6 DIFFICULTIES ASSOCIATED WITH CONVENTIONAL PRACTICES

12.6.1 General

This section contains conventional design practices and some of the design and installation problems associated with these practices. Alternative design practices are outlined in *Section 12.8 – Alternative Design Practices*.

12.6.2 Watermains & Water Distribution

The governing factor affecting the design depth of watermain and service connection installations in Ontario is the necessity to protect the pipe and its contents from the effects of frost.

Accepted practice has been to locate the watermain or service connection at such a depth that it is either below the frost line or the incidence of frost-related failures is at an acceptable level. The required burial depth (i.e., frost penetration depth) varies across the province from approximately 1.2 m (4 ft) to greater than 3.0 m (10 ft). The designer should refer to the National Research Council of Canada (NRC), Institute for Research in Construction (http://irc.nrc-cnrc.gc.ca) for information used to determine frost penetration.

The designer should be specifically aware that problems can arise when frost depth penetration values are applied without an adequate factor of safety in an effort to minimize the high cost of excavation and hence watermain installation costs where watermains are installed in trenches blasted in rock or areas with high water level conditions.

The water service connection is the most common place where freezing will occur due to the small size of pipe and the fact that the water does not flow at all times. It is not uncommon practice to alleviate this problem by bleeding individual services by leaving a tap running in the individual home with flows of 2,600 to 3,100 L (685 to 820 USgal) per home per day discharging to the sewer. The practice of bleeding places an extraordinary burden on water supply and sewage facilities.

12.7 RETROFITTING OF EXISTING SYSTEMS

12.7.1 General

There are several improvements which may be applied to the upgrading of existing services in areas subject to challenging conditions. These recommendations are supplementary to the appropriate sections of *Chapter 8 – Treated Water Storage* and *Chapter 10 – Distribution Systems*.

It is recommended that conditions of no snow cover be assumed for purposes of determining the maximum depth of frost. In many cases the system may be located partially in the frost zone, however, as long as the water is kept moving the system will not freeze. At dead ends, fire hydrants, and some service connections, where the freezing water may not be replaced, additional frost protection should be provided.

An additional concern exists regarding the increased loading on the pipe due to frost. Accordingly, the design of watermains in areas where the frost is experienced should include an allowance for this frost loading.

12.7.2 Water Distribution

12.7.2.1 System Layout

Where water services are located either partially or totally within the frost zone, and where it is not possible to eliminate dead end watermains, there are two possible solutions utilizing conventional design practices. The first is to insulate the watermain and the other is the replacement of the freezing water within the system by ensuring a constant flow of water through a recirculation pipe or a municipally controlled bleeder.

12.7.2.2 Service Connections

Service connections are the most common point where freezing will occur within any distribution system. There are several contributing factors, such as:

- The water service is subject to prolonged periods (e.g., overnight) of no-flow, thereby resulting in excessive cooling of the water; and
- Inadequate installation depths because of the cost of excavating in rock and/or in a zone of excessive frost depth.

In instances where repeated problems with freezing services have occurred or uncontrolled bleeders are in use to prevent freezing, the following alternatives may be considered:

a) Re-laying of the entire service connection at an adequate depth of cover;
b) Replacement of the entire service connection with a new service connection installed in a pre-insulated service duct, with thermostatically controlled heat tracing if required;
c) Provision of insulation over the existing service connection, with heat tracing if required; or,
d) Installation of a municipally controlled bleeder.

The preferred alternative in areas with deep frost penetration and rock trenches is (b) above. Alternative (d) is the least desirable, particularly when widespread problems are being encountered in the system. The designer may consider this alternative where occasional problems recur. When such a device is used, the bleeder installation should be accompanied by a water meter.

12.7.2.3 Insulation

Rigid slab insulation placed above the water pipe has been used with some success as an alternative to burying the pipe below the frost zone. Its main application has been in attempting to correct existing freezing problems at hydrants and other dead ends and in situations where the cover over an existing watermain is reduced due to the reconstruction of the road or regrading.

Caution must be exercised in the use of flat slab insulation and it should only be used when there is a reasonable heat source from high groundwater from below the pipeline.

When rigid slab insulation is to be used to provide frost protection, the thickness of the slab must be carefully determined. The thickness is, in effect, replacing natural cover, thereby permitting reduced construction depths or providing additional protection.

Based upon average conditions, the thickness of slab provided in an installation should be the equivalent of 25 mm (1 in) for every 300 mm (12 in) reduction in the depth of cover [i.e., approximately 83 mm (3 in) for every 1.0 m (3 ft) reduction].

It is recommended that the flat slab insulation be laid in 50 mm (2 in) thicknesses with joints offset by half the width of board in progressive layers.

As the frost penetration depth increases, the width of insulation required also increases. It may become more economical to provide an inverted "U" or box type of slab insulation or use insulated pipe. The former two methods are extremely labour intensive and close field supervision is required to ensure the structural soundness of the "U" or the box.

12.7.2.4 Bleeders

Bleeders should only be utilized as a last resort on existing systems, and should be under the strict control of the municipality or operating authority, regardless of their location.

Bleeders associated with dead end watermains should be designed with the discharge of bleeder flow to a ditch, if this is feasible without creating nuisance icing conditions. If such a point of discharge is unavailable, the bleeder may be discharged to an adjacent sewer, through an air gap backflow preventer.

Individual bleeders installed on private service connections should be located downstream of the water meter with discharge to a sewer through an air gap backflow preventer. This bleeder should be equipped with a corporation seal and activated by authorized personnel only. Another alternative is a factory manufactured automatic flow control or balancing valve.

12.8 ALTERNATIVE DESIGN PRACTICES

12.8.1 General

The cost of installing water services increases as the depth to bury increases. As discussed in *Section 12.6 – Difficulties Associated with Conventional Practices*, in areas that are subject to the effects of challenging conditions (such as the presence of rock, extreme frost or a high water table) the costs would be much greater as the depth to which these services need to be installed increases.

12.8.2 Thermal Considerations

When dealing with services and/or mains that are located in the active frost zone, it is possible to reduce heat loss and increase time before freezing by using pre-insulated piping with or without electric heat tracing.

12.8.3 Shallow Buried Pre-insulated Servicing Systems

"Shallow buried" means a system that is partially or totally within the frost zone (i.e., cover only for physical protection) and "insulated" means reducing the heat loss from the pipe by applying various amounts of insulation to the buried pipe.

In addition to the insulation, varying amounts of heat can be added to the service by inducing circulation or adding supplementary heat (e.g., heat tracing or hot water).

The preferred system is the "factory fabricated, pre-insulated, flexible piping system".

12.8.4 Water System Design

12.8.4.1 General

The fundamental concepts of water distribution system design and appurtenances should follow the recommendations contained in *Chapter 8 – Treated Water Storage* and *Chapter 10 – Distribution Systems*.

12.8.4.2 System Layout

While straight line grid systems are preferred, the designer should consider routing flexibility to avoid a challenging condition such as exposed rock by utilizing unconventional alignments. It is advisable to consider an alternative to the road allowance alignment such as the ditch line of the road where it is not snow-ploughed, or the use of parallel front yard or backyard easements.

In areas where the water service will be located either partially or totally within the frost zone and where it is not possible to eliminate dead end watermains, there are several alternatives available to reduce the probability of frost problems, as follows:

- Construction of the facility with a pre-insulated pipe package with heat tracing or an external thaw tube;

- Insulation of the water service with slab type insulation with or without a circulation line;
- Design of the system to include an induced flow via either a recirculation system or as a last resort, a municipally controlled bleeder; or,
- A combination of the above.

As has been noted in *Section 12.7.2.4 – Bleeders*, bleeders should only be utilized as a last resort, and be under the control of the municipality. Where a bleeder is the only alternative, the designer may consider the use of the last private connection as the bleeder in a controlled, heated environment.

12.8.4.3 Insulation of Watermains & Services

The preferred alternative for a shallow buried, thermally insulated water distribution system is to employ a factory-fabricated, pre-insulated package type piping system.

There are three basic options for a factory-fabricated, pre-insulated flexible piping system:

- Pre-insulated piping system without heat tracing or an external thaw tube;
- Pre-insulated piping system with heat tracing; and
- Pre-insulated piping system with an external thaw tube.

Similarly, there are two basic types of factory-fabricated pre-insulated service connection pipe:

- Individually insulated service connection (either with or without heat tracing); and
- Pre-insulated duct with a single service connection inserted, without unions, within the duct (either with or without heat tracing).

The heat tracing cable for either of the above pipe systems can have two functions, depending upon the design requirements: it can thaw the pipe once it has frozen (passive tracing – no thermostat), or it can be used to prevent the water in the pipe from freezing (active tracing – thermostatic control).

Since the thermal resistance of plastic is significant (125 times that of steel), the heat tracing density for plastic pipes should be considered carefully. The designer should consult the manufacturer of the factory insulated pipe system for guidance.

The insulation and its jacket material should have a higher density than the surrounding soil to be able to withstand the trench and service loadings without subjecting the service or duct pipe to excessive deflections or compression. Rigid polyurethane foam is recommended.

12.8.4.4 Pipe Materials

The designer should specifically consider the ability of the pipe joint to maintain "zero" leakage over the long term when subjected to frost action and the ability of the pipe material itself to resist structural damage or failure when subjected to inadvertent freezing and/or frost action such as frost heave or differential loading.

It is recommended that the purchase of a pre-insulated pipe package should be from a single source. This single source manufacturer should supply and guarantee the total package including carrier pipe, insulation, jacketing, heat trace cable and thermostatic controls. In addition, the manufacturer should be required to provide in-field service and technical expertise.

The provision of active heat tracing is generally not needed on large diameter watermains and forcemains [i.e., diameter above 150 mm (6 in)] and may not be needed on smaller diameters within the public right-of-way, provided the water is kept moving. A minimum acceptable time-to-freeze of approximately 96 hours should be considered an acceptable level of risk. The final decision in this regard rests with the designer and the municipality/owner.

Where the time-to-freeze is less than 96 hours or a dead end watermain or water service connection is involved, it is recommended that thermostatically controlled (solid state) heat trace cable be provided (active heat tracing).

Where it is determined that it is necessary or advisable to provide active heat tracing on main lines, as opposed to service connections, the designer should consider:

- Available voltage and "power points";
- Maximum heat cable circuit length; and
- Power consumption (if electricity is extremely costly, consider constant wattage cable which only draws power when absolutely required).

When the time to freeze is greater than 96 hours, it is recommended that a manually activated heat trace cable or an external thaw tube (passive thaw system) be provided. A passive system would only be activated when the freezing had occurred.

Thawing equipment is available from a number of suppliers.

12.8.4.5 Service Connections

All new water service connections which are installed within the frost zone should be constructed in a pre-insulated HDPE duct with active heat tracing and a thermostatic control. Bleeders should not be employed as a method of freeze protection on new services.

Where heat tracing is to be provided, factors such as type of heat trace cable, cable jacketing and thermostats should be considered.

The installation of proprietary domestic systems which heat and/or recirculate water within the service line may also be considered for individual connections that may be prone to freezing. Adequate backflow prevention should be provided.

12.8.4.6 Installation Details

The fundamentals of pre-insulated pipe installation are similar for this type of pipe as for a conventional pipe installation. However, several additional features should be included on shallow buried, pre-insulated systems as follows:

- Pre-insulated pipe should not be buried with less than 0.6 m (2 ft) cover when it will be subjected to vehicular loadings (i.e., driveways and highway crossings) without the provision of additional protection for the pipe. This protection can take the form of either a metal or plastic jacketed pipe installed within a culvert section(s);
- A nominal 50 mm x 200 mm (2 in x 8 in) warning board should be placed 150 mm (6 in) above any pre-insulated pipe with less than 1.2 m (4 ft) cover in order to afford protection to the pipe and warn excavators;
- Sand bags should be placed between the pipe and the trench wall, when the pipe is being installed in a rock trench on a long radius deflection or curve;
- The pipe design should include a check for buoyancy in areas where the pipe will be located at or below the groundwater table; and
- The pipe should be snaked in the trench in order to allow for expansion and contraction.

12.8.4.7 Fittings & Appurtenances

When a shallow buried, thermally insulated type system is proposed, special consideration must be given to both the type of fitting proposed and its proper installation.

Valves
Low thermal conductivity valve box materials with valve system extension pieces should be used.

Chambers
Where it is necessary to provide valve or meter chambers, the chambers should be adequately insulated, provided with frost covers in the access hatches, the pipe proper should be insulated and, when necessary, heat traced. The chamber design should incorporate all safety features for access/egress and emergency evacuation situations.

Bends & Tees
Where ductile iron fittings are used with mechanical joint fittings, restraining type glands should be utilized as opposed to concrete thrust blocks to better facilitate either factory applied or field applied insulation. The insulation should be coated with a suitable moisture barrier.

High density polyethylene pipe can be adapted to this type of system through the use of thermally butt fused end flanges connected to flanged to plain end ductile iron pipe filler pieces.

Hydrants
Hydrants and their leads are essentially a dead end watermain and must, therefore, be accorded special attention. The importance of this special attention is reinforced by the necessity of maintaining the hydrant operational year round.

The simplest and most effective way of protecting the hydrant assembly is to locate the watermains off the traveled road allowance (i.e., within the ditch line or easements), and close couple the hydrant assembly to the tee and shut-off valve assembly and insulate the barrel.

12.8.4.8 Single-Pipe Recirculation System

The single-pipe recirculation system consists of one or more uninterrupted loops or sub-loops originating at a recirculation facility and returning to that facility.

The design of such a system should minimize the length of pipe required and, in turn, minimize energy losses.

This system allows for positive simple control of the distribution system via the installation of flow, pressure and temperature monitoring on the return line(s) at the recirculation facility. The rate of recirculation is controlled by the supply and return temperatures. The actual variation in rate can be accomplished via either the use of a pressure reducing, pressure sustaining type valve, turning additional pumps on or a combination of these.

Supply temperatures should be in the order of 4 to 7°C (39 to 45°F) with return temperatures between 1 to 2°C (34 to 36°F). In some instances, pretempering (i.e., pre-heating) of the supply water may be required. This can be accomplished, when necessary, via the use of a supplementary water heater.

As the length of the loop increases, the risk of service loss also increases in case of a shutdown due to a problem along the line. The designer should consider short loop links installed at strategic locations to break the main loop. These links should be valved off to allow the pipe to be left empty. In case of an emergency, these links can be opened to reroute the flow of water and possibly isolate the break.

The single-pipe recirculation system can be designed to supply water in the normal return line as well as the supply line under fire conditions. For this reason, the return line should not decrease drastically in size.

The recirculating facility can be located at the source or in a separate pumping facility, or a combination of the two.

By planning community growth in a dense circular pattern, maximum efficiency can be made of this method of servicing.

Back-of-lot mains are preferred if possible. If the mains are placed in the street, the appurtenances (e.g., valve boxes) are subject to physical damage.

Placing the mains at the rear lot line reduces service line connections and permits service lines of equal length on both sides of the main. With mains in the road allowances, usually to one side, services are of unequal length.

A further advantage of mains located along the rear lot line is that the manholes containing water line valves and hydrants and freeze protection controls can be elevated in cylindrical shape approximately 1.0 m (3 ft) above grade. This allows easier access during the winter as the immediate area around the elevated manhole is often blown clear of snow.

APPENDICES

Appendix A	GLOSSARY
Appendix B	UNITS OF MEASURE
Appendix C	ACRONYMS & ABBREVIATIONS
Appendix D	TABLE OF REFERENCES

APPENDIX A

GLOSSARY

1. **Aeration.** Aeration systems add air to water and can be used to oxidize taste and odour-causing compounds or iron.

2. **Air stripping.** Air stripping systems remove gases from water and may be used to remove objectionable concentrations of dissolved gases (e.g., hydrogen sulphide, carbon dioxide), trihalomethanes or volatile organic compounds (VOCs).

3. **Areal Standard Unit (ASU) Count.** A unit of measurement used in the evaluation of the number of aquatic plankton, frequently algae, in water (this number is sometimes called the standing crop). A small volume of water is examined microscopically and the number of areal standard units counted. One areal standard unit is equal to four small squares in a Whipple grid at a magnification of 200. Areal standard units represent the number per unit volume.

4. **Backflow.** A hydraulic condition, caused by a difference in pressures, which causes nonpotable water or other fluid to flow into a potable water system.

5. **Backpressure.** A pressure that can cause water to backflow into the water supply when a user's water system is at a higher pressure than the public water system.

6. **Backsiphonage.** A form of backflow caused by a negative or sub-atmospheric pressure within a water system.

7. **Blowdown.** (1) The continuous or intermittent removal of a portion of any process flow to maintain the constituents of the flow within desired levels. (2) The water discharged from a boiler, cooling tower or membrane water treatment system to dispose accumulated dissolved solids.

8. **Capacity.** The flow rate that a treatment process unit or process train or treatment plant is capable of producing. **See also *gross capacity*, *net capacity*** and ***rated capacity*.**

9. **Carbon usage rate.** A measure of the capacity of granular activated carbon or powdered activated carbon to remove a contaminant to a specified level. Usage rates are often expressed in terms of weight of activated carbon used per unit volume treated.

10. **Cavitation.** The formation and sudden collapse of vapour bubbles in a liquid, usually resulting from local low pressures, as on the trailing edge of a propeller. This phenomenon develops a momentary high local pressure that can mechanically destroy

a portion of a surface on which the bubbles collapse. Cavitation can occur in pumps when the suction side has insufficient head for the current.

11. **Certificate of Approval.** A legal instrument issued by a Director under the *Safe Drinking Water Act, 2002* to the owner of a municipal drinking-water system to authorize the establishment, replacement, alteration, use and operation of the system. With the implementation of the Licensing Program, a C of A will be replaced by a combination of a *Drinking Water Works Permit* (DWWP) for the establishment or alteration of the system and a *Municipal Drinking Water Licence* (Licence) to authorize the use and operation of the system.

12. **Chemically enhanced backwash.** Backwashing of a membrane with the addition of chlorine or other chemicals. Also referred to as maintenance clean or wash, enhanced flux maintenance, or extended backpulse clean.

13. **Clean-in-place (CIP).** A chemical cleaning process in which the membrnes in a membrane water treatment system (1) are not removed from their housings (pressure vessels) or the system and (2) are cleaned by being exposed to cleaning solutions, which are commonly recirculated through the cleaning system and membranes.

14. **Clearwell.** A tank or vessel used for storing treated water. Typical examples of storage needs include (1) finished water storage to prevent the need to vary the rate of filtration with variations in distribution system demand, and (2) backwash water for filters. Clearwells are located on-site at a water treatment plant. A clearwell is also called a filtered-water reservoir.

15. **Coagulant aid.** A chemical added during coagulation to improve the process by stimulating floc formation or by strengthening the floc so it holds together better. Such a chemical is also called a flocculant aid.

16. **Compound gauge.** A compound gauge is used to measure atmospheric and vacuum pressure. The vacuum pressure is generally measured in mm of Hg. Atmospheric pressure is measured in kilopascals (kPa) or pounds per square inch (psi).

17. **Concentrate.** The concentrated solution containing constituents removed or separated from the feedwater by a membrane water treatment system. Concentrate is also called reject, brine, retentate or blowdown, depending on the specific membrane process.

18. **Contaminant.** Any physical, chemical, biological or radiological substance or undesirable matter in water.

19. **Continuous monitoring equipment.** Equipment that, at intervals appropriate for the process and parameter being monitored, automatically tests for the parameter directly in the stream (or in the case of UV application, through the stream) of water being

treated or distributed, or in a continuous sample taken from the stream of water being treated or distributed, where a continuous sample is a continuous stream of water flowing from the stream of water being treated or distributed to the monitoring equipment.

20. **Cross-connection.** The physical connection of a safe or potable water supply with another water (e.g. wastewater, treatment chemicals, or raw or partially treated water) supply of unknown or contaminated quality or such that the potable water could be contaminated or polluted.

21. **CT.** The product of disinfectant concentration (in milligrams per litre) determined before or at the first customer and the corresponding disinfectant contact time (in minutes). Units are milligram minutes per litre.

22. **Demand.** The amount of water used by consumers during a certain time interval from a water system.

23. **Disinfection by-products (DBP).** A chemical by-product of the disinfection process. Disinfection by-products are formed by the reaction of the disinfectant, natural organic matter and the bromide ion (Br-). Some disinfection by-products are formed through halogen (e.g., chlorine or bromine) substitution reactions; i.e., halogen-substituted by-products are produced. Other disinfection by-products are oxidation by-products of natural organic matter (e.g., aldehydes-RCHO). Concentrations are typically in the microgram-per-litre or nanogram-per-litre range.

24. **Disinfection Procedure.** *Procedure for Disinfection of Drinking Water in Ontario* (PIBS 4448e01).

25. **Downsurge.** Pipeline pressure surge, which is negative because its magnitude is below the normal operating pressure of the pipeline.

26. **Drinking-water system.** A system of works, excluding plumbing, that is established for the purpose of providing users of the system with drinking water and that includes:
    (a) Anything used for the collection, production, treatment, storage, supply or distribution of water;
    (b) Anything related to the management of residue from the treatment process or the management of the discharge of a substance into the natural environment from the treatment system; and
    (c) A well or intake that serves as the source or entry point of raw water supply for the system.

27. **Drinking Water Works Permit (DWWP).** A legal instrument issued by a Director under the *Safe Drinking Water Act* to the owner of a municipal drinking-water system to authorize the establishment, replacement or alteration of the system. With the

implementation of the Licensing Program, the Certificate of Approval (C of A) will be replaced by a combination of a *Drinking Water Works Permit* (DWWP) for the establishment or alteration of the system and a *Municipal Drinking Water Licence* (Licence) to authorize the use and operation of the system.

28. **Elevated tank.** A water storage facility located on and supported by a tower constructed at an elevation to provide useful storage and pressure for a water pressure plane.

29. **Empty bed contact time (EBCT).** A standard convention or measure of the time during which a water to be treated is in contact with the treatment medium. The empty bed contact time is calculated by dividing the empty volume in a contactor that will be occupied by the treatment medium by the flow rate:

    EBCT = V/Q
    Where (in any consistent set of units):
    V = the volume of the vessel
    Q = the flow rate

    Because the treatment medium, such as granular activated carbon, will occupy some volume, the empty bed contact time overestimates the actual time that the flow resides in the contactor.

30. **Fire protection.** The ability to provide water through a distribution system for fighting fires in addition to meeting the normal demands of water usage.

31. **Floating storage (floating on the system).** A method of operating a water storage facility such that daily flow into the facility approximately equals the average daily demand for water. When consumer demands for water are low, the storage facility will be filling. During periods of high demands, the facility will be emptying.

32. **Flux.** For a membrane separation process, the volume or mass of permeate passing through the membrane per unit area per unit time. Solvent (water) flux rate is commonly expressed in gallons per square foot per day, or cubic metres per square metre per second, or metres per second.

33. **Gross capacity.** The maximum flow rate into a treatment process unit or process train or treatment plant while producing treated water of acceptable quality.

34. **Groundwater.** The water contained in interconnected pores located below the water table in an unconfined aquifer or in a confined aquifer. For the purpose of this document, a raw water supply which is groundwater means water located in subsurface aquifer(s) where the aquifer overburden and soil act as an effective filter that removes microorganisms and other particles by straining and antagonistic effect, to a level where the water supply may already be potable but disinfection is required as an additional health risk barrier, unless the ministry has granted a drinking-water

system relief, or requirements for exemption have been met in accordance with O. Reg. 170/03.

35. **Groundwater under Direct Influence of Surface Water (GUDI).** Groundwater having incomplete/undependable subsurface filtration of surface water and infiltrating precipitation.

36. **Gt.** The product of the velocity gradient, G (expressed in units per second), and the flocculation or mixing times (in seconds).

37. **Hydropneumatic tank (or pressure tank).** A tank that is used in connection with a water distribution system for a single household, for several houses, or for a portion of a larger water system, which is airtight and holds both air and water, and in which the air is compressed and the pressure is transmitted to the water.

38. **Instantaneous flow rate.** A flow rate of water measured at particular instant, such as by a metering device.

39. **L10.** The predicted service life, for a given population of identical bearings operating under controlled conditions, for which 90% will meet or exceed the predicted life, and 10% will fail before reaching that value.

40. **Langelier saturation index.** The most known of the calcium carbonate ($CaCO_3$) saturation indexes, the formula for the Langelier index is based on a comparison of the measured pH of a water (pHa) with the pH the water would have (pHs) if at saturation with $CaCO_3$ (calcite form) given the same calcium hardness and alkalinity for both pH cases. The basic formula is LSI = pHa – pHs.

41. **Material safety data sheet (MSDS).** Information on the use, handling and storage of specific chemicals or products. Material safety data sheets contain mandated types of information concerning physical characteristics, reactivity, required personal protective equipment and other safeguards.

42. **Mass transfer zone (MTZ).** The place in an adsorption or ion exchange bed where the concentration of adsorbate in solution is changing with depth. The concentration gradient corresponds to the gradual transition of the adsorbent or ion exchange resin from fresh (or virgin) to spent (or exhausted). Aeration or air-stripping columns also have mass transfer zones as the gas or liquid changes from under-saturated to the equilibrium concentration with height.

43. **Membrane backwash.** A cleaning operation that typically involves periodic reverse flow to remove particulate accumulated on the membrane surface. Also referred to as backpulse, backpulse clean, or flux maintenance.

44. **Membrane reject.** The material retained or filtered out by the membrane. Also known as membrane concentrate.

45. **Ministry.** The Ontario Ministry of the Environment.

46. **Municipal Drinking Water Licence.** A legal instrument issued by a Director under the *Safe Drinking Water Act* to the owner of a municipal drinking-water system to authorize the use and operation of the system. With the implementation of the Licensing Program, the Certificate of Approval (C of A) will be replaced by a combination of a *Drinking Water Works Permit* (DWWP) for the establishment or alteration of the system and a *Municipal Drinking Water Licence* (Licence) to authorize the use and operation of the system.

47. **Muskeg.** A bog, usually a sphagnum bog, frequently covered with grassy tussocks, growing in wet, poorly drained boreal regions, often in areas of permafrost.

48. **Net capacity.** The daily flow rate from a treatment process or treatment plant accounting for process losses and in-plant water uses, as well as otherwise productive time that a unit or process train is off-line for backwash, routine maintenance or repair.

49. **Net positive suction head (NPSH).** A measure of the pressure at the suction side of the pump, including atmospheric pressure and vapour pressure of the liquid being pumped.

50. **Peak demand.** The maximum momentary load (expressed as a rate) placed on a water treatment plant, distribution system or pumping station. It is usually the maximum average flow in one hour or less, but it may be specified as instantaneous.

51. **Permeate.** For a pressure-driven membrane treatment process, the portion of the feed solution that passes through the membrane.

52. **Point of impingement.** Any point on the ground or on a receptor, such as nearby buildings, located outside the emitter's property boundaries at which the highest concentration of a contaminant caused by the aggregate emission of that contaminant from a facility is expected to occur.

53. **Primary disinfection.** A process or a series of processes intended to remove and/or inactivate human pathogens such as viruses, bacteria and protozoa, potentially present in influent water before the water is delivered to the first consumer.

54. **Rated capacity.** Volume of treated water that meets all applicable Ontario drinking water quality regulations including the aesthetic water quality objectives and that may be made available by the water treatment plant for delivery to the drinking-water distribution system in any 24 hour period (usually provided as a rate in m^3/d).

55. **Rate controlling step.** The slowest elementary process in a sequence. The products of a sequence of processes can be formed no faster than the rate of the slowest step in the sequence. Therefore, if one of the steps in a sequence is much slower than all the others, the rate of the overall reaction will be limited by, and be exactly equal to, the rate of this slowest step.

56. **Raw water.** Water from the supply source prior to treatment.

57. **Recovery clean.** Recirculating a cleaning solution and/or soaking the membranes in a cleaning solution to restore the membrane transmembrane pressure. Also known as clean-in-place (CIP).

58. **Recovery rate.** In a membrane water treatment system, the fraction of the feedwater that is converted to permeate, filtrate or product. Recovery is sometimes called permeate recovery, product water recovery, feedwater recovery, or conversion.

59. **Residuals.** (1) Any gaseous, liquid, or solid by-product of a treatment process that ultimately must be disposed of. For example, in a fixed-bed filter for removing particles from water, both the filter backwash water and the solids in the backwash water are residuals. A residual is often called a sludge. (2) The concentration of free available disinfectant (chlorine) remaining after a given contact time under specified conditions or treatment chemical after the final process (i.e. in the treated water).

60. **Secondary disinfection.** The maintenance of a disinfectant residual in the distribution system to protect the water from microbiological re-contamination, reduce bacterial re-growth, control biofilm formation, and serve as an indicator of distribution system integrity (loss of disinfectant residual indicating that the system integrity has been compromised). Only chlorine, chlorine dioxide and monochloramine provide a persistent disinfectant residual and can be used for the maintenance of a residual in the distribution system.

61. **Sludge.** A term that is being replaced by the term residuals. It has the following meanings: (1) The accumulated solids separated from a liquid, such as water, during processing. (2) Organic deposits on the bottoms of streams or other bodies of water. (3) The removed material resulting from chemical treatment, coagulation, flocculation, sedimentation, or flotation (in which case the sludge is called float) of water. (4) Any solid material containing large amounts of entrained water and collected during water treatment.

62. **Specific throughput.** The volume of water passed through an ion exchange resin bed or water treatment system before the exchanger or system reaches exhaustion.

63. **Standpipe.** A high tank, usually small in diameter compared to height, for holding water. This water is used to maintain pressure in a water supply system and as storage for fire protection.

64. **Storage tank.** A compartment used to accumulate the product water from a water treatment unit so that sufficient quantity, pressure, or both are available for intermittent periods of higher flow rate water use.

65. **Surface Water.** Water bodies (lakes, wetlands and ponds, including dug-outs), water courses (rivers, streams, drainage ditches), infiltration trenches and areas of temporary precipitation ponding.

66. **T10.** The length of time during which not more than 10% of the influent water passes through a process. The use of T10 ensures that 90% of the water will therefore have a longer contact time.

67. **Tank.** A structure or container used to hold solids or liquids for such purposes as aeration, disinfection, equalization, holding, sedimentation, treatment, mixing, dilution, feeding, or other handling of chemical additives.

68. **Technical Support Document.** *Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines* (PIBS 4449e01).

69. **Total dynamic head (TDH).** The difference in height between the hydraulic grade line on the discharge side of the pump and the hydraulic grade line of the suction side of the pump. This head is a measure of the total energy that a pump must impart to the water to move it from one point to another.

70. **Treated water.** Water that has been subjected to treatment processes.

71. **Turndown ratio.** The ratio of the design range of an instrument to the range of acceptable accuracy or precision.

72. **Velocity Gradient (G).** A measure of the mixing intensity in a water process. The velocity gradient, which is expressed in units per second, is dependent on the power input, the viscosity and the reactor volume. Very high velocity gradients (greater than 300 per second) are used for complete mixing and dissolution of chemicals in a coagulation process, whereas lower values (less than 75 per second) are used in flocculation to bring particles together and promote agglomeration.

73. **Water works.** Any part of a drinking-water system including collection, production, treatment, storage, supply and distribution of water, or any part of such works.

74. **Watershed.** The drainage basin area contained within the bounds specified by a divide and above a specified point on a stream. A watershed is also called a catchment area, drainage area or drainage basin.

75. **Wet Well.** A pumping wet well is used to ensure that a minimum volume is available to be pumped to subsequent unit processes or the distribution system. The level in the

wet well may vary, and the pumping rate may be changed, to respond to needed changes in the flow rate and to permit continuous plant operation.

APPENDIX B

UNITS OF MEASURE

Units of Measure

Short form	Long form
°C	degree Celsius
°F	degree Fahrenheit
ft	foot
ft/s	foot per second
ft/min	foot per minute
ft/h	foot per hour
$\text{ft}^3/(\text{min}\cdot\text{ft}^2)$	cubic foot per minute per square foot
scfm	standard cubic foot per minute
USgal	USgallon
$\text{USgal}/(\text{ft}^2\cdot\text{day})$	USgallon per square foot per day
USgpm	USgallon per minute
USgpm/ft^2	USgallon per minute per square foot
USgpm/ft	USgallon per minute per linear foot
gr/ft^3	grain per cubic foot
hr	hour
in	inch
kg/m^2	kilogram per square metre
$\text{kg}/(\text{m}^2\cdot\text{d})$	kilogram per square metre per day
kPa	kilopascal
kW	kilowatt
lb/ft^2	pound per square foot
$\text{lb}/(\text{ft}^2\cdot\text{d})$	pound per square foot per day
L/(cap·d)	litre per capita per day
$\text{L}/(\text{m}^2\cdot\text{day})$	litre per square metre per day
L/s	litre per second
L10	basic-rated life in hours or millions of revolutions
mi	mile

Units of Measure

Short form	Long form
mL	millilitre
m	metre
m/s	metre per second
m/min	metre per minute
m/h	metre per hour
m^3/d	cubic metre per day
m^3/(ha·d)	cubic metre per hectare per day
m^3/(m·h)	cubic metre per metre per hour
m^3/(min·m^2)	cubic metre per minute per square metre
m^3/(m·d)	cubic metre per metre per day
m^3/(m^2·d)	cubic metre per square metre per day
m^3/(m^2·s)	cubic metre per square metre per second
mL/m^3	millilitre per cubic metre
mg/L	milligram per litre (parts per million)
mm	millimetre
nm	nanometre
psi	pound-force per square inch
µm	micrometre

APPENDIX C

ACRONYMS & ABBREVIATIONS

Acronyms & Abbreviations

Short form	Long form
ANSI	American National Standards Institute
AOP	Advance oxidation process
APHA	American Public Health Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASU	Areal standard units
AWWA	American Water Works Association
AwwaRF	American Water Works Association Research Foundation
CGSB	Canadian General Standards Board
C of A	Certificate of Approval
CIP	Clean-in-place
CSA	Canadian Standards Association
CSCE	Canadian Society for Civil Engineering
CT	see Glossary
CWA	Clean Water Act, 2006
DAF	Dissolved air flotation
DE	Diatomaceous earth
DBP	Disinfection by-product
DC	Direct current
DOC	Dissolved organic carbon
DVGW	Deutsche Vereinigung des Gas- und Wasserfaches (German Technical and Scientific Association for Gas and Water)
DWWP	Drinking Water Works Permit
EAA	Environmental Assessment Act
EAAB	Environmental Assessment and Approvals Branch
EBCT	Empty bed contact time

Acronyms & Abbreviations

Short form	Long form
EBR	Environmental Bill of Rights
EPA	Environmental Protection Act
ESR	Environmental Study Report
FCM	Federation of Canadian Municipalities
FED-STD 595B	Federal Standard 595B Colors Used in Government Procurement (USGSA)
GAC	Granular activated carbon
GFI	Ground fault interrupter
HAA	Halo Acetic Acid
HDPE	High density polyethylene
HMI	Human machine interface
HVAC	Heating, ventilating, and air conditioning
IC	Infrastructure Canada
LAN	Local area network
LOX	Liquid oxygen
LPHO	Low pressure high output (UV lamp)
MCEA	Municipal Engineers Association [of Ontario] Municipal Class Environmental Assessment
MF	Microfiltration
MNR	Ontario Ministry of Natural Resources
MOE	Ontario Ministry of the Environment
MP	Medium pressure (UV lamp)
MSDS	Material Safety Data Sheet
MTZ	Mass transfer zone
NDMA	N-nitrosodymethylamine
NMA	Nutrient Management Act
NPSH	Net positive suction head
NRC	National Research Council
NSF	NSF International (National Sanitation Foundation)
NTU	Nephelometric turbidity unit
NWRI	National Water Research Institute

Acronyms & Abbreviations

Short form	**Long form**
ON ÔNorm	Österreichisches Normungsinstitut (Austrian Standards Institute)
OPS	Ontario Provincial Standards for Roads and Public Works
OPSS	Ontario Provincial Standards Specification
OWRA	Ontario Water Resources Act
P&ID	Process and instrumentation diagrams
PAC	Powdered activated carbon
PCN	Process control network
PEO	Professional Engineers of Ontario
PFD	Process flow diagrams
PIT	Pressure indicating transmitter
PRV	Pressure regulating valve
PSA	Pressure swing adsorption
PVC	Polyvinyl Chloride
SDWA	Safe Drinking Water Act
SOR	Surface overflow rate
RTC	Real-Time Control
TCU	True colour units
TDH	Total dynamic head
THM	Trihalomethane
THMFP	Trihalomethane formation potential
TOC	Total organic carbon
TSSA	Technical Standards and Safety Authority
TWL	Top water level
T10	see Glossary
SCADA	Supervisor control and data acquisition
SDS	Simulated distribution system
UF	Ultrafiltration
UNS	Unified Numbering System for Metals and Alloys
UPS	Uninterruptible power supply

Acronyms & Abbreviations

Short form	Long form
USEPA	United States Environmental Protection Agency
USGSA	United States General Services Administration
UTM	Universal Transverse Mercator
UV	Ultraviolet light
UVT	UV transmittance
VAC	Volts of alternating current
VFD	Variable frequency drive
VSA	Vacuum swing adsorption
WEF	Water Environment Federation
WTP	Water treatment plant

APPENDIX D

TABLE OF REFERENCES

Ministry Legislation

Clean Water Act, 2006 (CWA) 1-1, 4-1
Environmental Assessment Act (EAA) 1-1, 2-1, 2-2
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Environmental Protection Act (EPA) 1-1, 3-2, 11-5
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Safe Drinking Water Act, 2002 (SDWA) .... passim

Ministry Regulations

Air Pollution - Local Air Quality (O. Reg. 419/05) 3-19, 6-5
Certification of Drinking-Water System Operators and Water Quality Analysts (O. Reg. 128/04) 5-24
Drinking-Water Testing Services Regulation (O. Reg. 248/03) 3-21
Financial Plans (O. Reg. 453/07) 1-3
General (O. Reg. 267/03) 11-5
Licensing of Municipal Drinking Water Systems (O. Reg. 188/07) 1-4
Ontario Drinking-Water Quality Standards (O. Reg. 169/03) .... passim
Water Taking and Transfer Regulation (O. Reg. 387/04) 3-11
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Ministry Requirements

Certificate of Approval (C of A) .... passim
Drinking Water Works Permit (DWWP) .... passim
Environmental Study Report (ESR) 2-2, 2-7, 3-11, *C-2*
Municipal Drinking Water Licence .... passim
Municipal Drinking Water Licensing Program *1-3*, *1-4*, *2-1*, *A-2*
Permit to Take Water (PTTW) 2-4, 3-11, 3-12, 4-10
Procedure for Disinfection of Drinking Water in Ontario (Disinfection Procedure) (PIBS 4448e01) .... passim
Sewer Use By-Law *11-1*
Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines (Technical Support Document) (PIBS 4449e01) .... passim

Ministry Documents

Development of Microbial Contamination Control Plans for Municipal Groundwater Supply Wells under Direct Influence of Surface Water with Effective in situ Filtration (PIBS 4008e) 4-9
Development of Microbial Contamination Plans (Interim Wellhead Protection Measures Plan) for Municipal Groundwater Supply Wells Under the Direct Influence of Surface Water with Effective in-situ Filtration - Guidance Document (PIBS 5023e) 4-9

Guide for Applying for Approval (Air and Noise) (PIBS 4174e) 6-5
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Model Microbial Contamination Control Plan for Municipal Groundwater Supply Wells Under the Direct Influence of Surface Water with Effective in situ Filtration - Reference Document (PIBS 5022e) 4-9
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Other Ontario Legislation & Regulations
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Confined Spaces Regulation (O.Reg.632/05) 7-8
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Fire Protection and Prevention Act, 1997 .... passim
Industrial Establishments (R.R.O 1990, Regulation 851) 3-27, 6-13
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Small Drinking Water Systems (O. Reg. 319/08) 1-2
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Transitional - Small Drinking Water Systems (O. Reg. 318/08) 1-2
Workplace Hazardous Materials Information System (WHMIS) (R.R.O. 1990, Regulation 860) 6-1, 6-5, 6-13
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Other Ontario Requirements
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Federal/National Legislation, Regulations, Codes & Requirements
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Hazardous Products Act 3-31, 6-5
Health Canada *Guidelines for the Management of Naturally Occurring Radioactive Materials* (NORM) 11-10
Material Safety Data Sheets (MSDS) 3-31, 6-5, A-5, C-2
Navigable Waters Protection Act 4-3, 10-18

Standards

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ANSI/HI Pump Standards 7-1, 7-4
APHA/AWWA/WEF *Standard Methods for the Evaluation of Water and Wastewater* .. 5-35
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NSF/ANSI *Standard 61: Drinking Water System Components - Health Effects* ...... passim
ON *ÖNORM M 5873* 5-41
Ten-State *Recommended Standards for Water Works* 5-43, 5-61

Guidance & Best Practice Documents

ASCE/CSCE Cold *Regions Utilities Monograph, 1996* 12-1, 12-2
AWWA *Emergency Power Source Planning for Water and Wastewater* 7-7
AWWA *Manual of Water Supply Practices M11 – Steel Water Pipe: A Guide for Design and Installation* 10-4

AWWA *Manual of Water Supply Practices M14 – Recommended Practice for Backflow Prevention and Cross-Connection Control* 3-28, 3-31, 6-13, 10-19
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